
Essays on the effects of government spending in the presence of skill accumulation through Learning-by-Doing

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Abstract

In this thesis I present a theoretical and empirical investigation of the effects and propagation mechanisms of a government spending shock with Learning-By-Doing (LBD). A positive government spending shock increases hours worked. By the LBD mechanism the increase in hours yields an increase in productivity and hence a decline in inflation and interest rates. The fall in the long-term real interest rate generates an inter-temporal effect leading my model results closer in line with the data.

In chapter 1 I first provide a literature review on the effects of a change in government spending. I then present a DSGE new Keynesian model with LBD and comment its main features. I show that, by including LBD, the model generates an increase in productivity and consumption in line with the empirical evidences.

Chapter 2 analysis the effect of a government spending shock on the real exchange rate. I show that including LBD makes the model able to reproduce the real exchange rate depreciation observed in the data. This result derives from the increase in consumption and the assumption of international risk sharing condition.

Chapter 3 investigates the effect of a government spending shock on housing market. I find Vector autoregression (VAR) evidence that house prices increase after a government spending shock. In a model where housing can be used by credit constrained households as collateral to borrow, the increase in housing wealth introduces an additional propagation mechanism for a government spending shock. I present a model with two sectors, heterogeneity in the households' discount factor, and credit constrained agents. I show that intro-

ducing the LBD mechanism, by contrast with a model where LBD is absent, makes the model able to replicate the observed increase of real house prices. The model is estimated by matching DSGE and VAR impulses responses.

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Introduction

In this thesis I present a theoretical and empirical investigation of the effects and propagation mechanisms of a government spending shock with skill accumulation of workers through past work experience or Learning-by-Doing (LBD). This thesis is made up of three chapters.

In chapter 1, I first present a review of the empirical evidences on the effects of a change in government spending on a set of selected variables. The correct identification of a government spending shock is a challenging econometrics task and the most appropriate identification strategy is still debated. I conclude that, despite the empirical literature has not yet provided a definitive answer, the most influential literature shows that an increment in government spending delivers Keynesian effects by generating an increase in output, hours, real wages and private consumption. Furthermore, positive changes in government spending are likely to be associated with a decrease in inflation and interest rate, and an increase in productivity. Yet, most of the theoretical models based on an infinite horizon representative agent deliver results at odd with the empirical evidences. In particular, in the last two decades there has been a growing interest in DSGE models. However, standard version of both Real Business Cycle (RBC) and New-Keynesian (NK) models, while successful in matching the observed increase in output and hours, fail to generate the increase in productivity and deliver a response of consumption of the wrong sign. Different solutions have been proposed to bring theoretical results closer in line with data. A general overview of these proposals is presented.

In the first chapter I present and discuss the solution proposed in this thesis to reconcile theoretical results and empirical evidences. I rely on New

Keynesian DSGE models. However, I depart from a standard model, like the one presented in Smets and Wouters (2007), by assuming that workers' skills are not constant but evolve according to a Learning-By-Doing mechanism as in Chang et al. (2002). I show that introducing LBD in an otherwise standard new-Keynesian DSGE model have important effects on the propagation mechanism of a government spending shock and enables the model to generate a response of consumption and productivity in line with empirical findings. In new Keynesian models, because of price frictions, those firms that cannot change price increase production and labour demand to meet the rise in aggregate demand caused by the increase in government spending. However, for the government budget constraint to hold, the increase in government spending must be matched with an equal increase in the discounted value of taxes which reduces the flow of available resources for the private sector. Rational agents, hit by this negative wealth effect, increase labour supply. Both with and without LBD the new equilibrium in the labour market is associated to an increase in hours worked and, under some circumstances, to a rise in real wages.¹ As the real wage rises, households increase labour supply and substitute consumption for leisure. Without LBD, this intra-temporal substitution effect is not strong enough to compensate for the negative wealth effect. Furthermore, in absence of LBD, the increase in the real wage raises marginal costs. The fraction of firms able to re-optimize their price will respond to the increase in marginal costs by setting a higher price. The gradual increase in the price level increments the expected path of inflation. The monetary authority reacts to changes in inflation by increasing the nominal interest rate. This translates into an increase in the real interest rate which brings about an inter-temporal effect that induces households to reduce current consumption and postpone it. In fact, despite the increase in hours, the output increase is not sufficiently large, hence private consumption have to fall to compensate the increase in government spending. With LBD, the increase in hours worked triggers an

¹As shown in Linnemann and Schabert (2003), in a model without LBD, if the central bank sets the nominal interest rate following a Taylor rule, wages can increase if there is no capital accumulation, or in a model with capital accumulation, the increase in real wage is still feasible if the nominal interest rate rule puts not too much weight on output.

increase in the workers skills level and hence in the level of productivity. The negative wealth effect is milder because the increase in productivity generates an higher level of resources available in the future. The LBD mechanism, by the increase in productivity, reduces firms marginal costs. This results in a fall of inflation and the real interest rate. The lower real interest rate reduces the return to saving and induces agents to increase current consumption. Furthermore, the boost in real wages, generated by the increase in productivity, incentives households to substitute consumption for leisure. Thus, the combination of inter and intra-temporal effects, based on the increase in productivity generated by the LBD mechanism, offset the negative wealth effect and the final result is an increase in consumption. I also show the crucial role played by nominal rigidities. Without wage frictions households are on their perfectly competitive labour supply and are less willing to substitute consumption for leisure. In addition, in absence of price frictions, firms can immediately change their price. The increase in productivity cannot exert any deflationary effect and the key propagation mechanism proposed is switched off.²

In the second chapter, I use the mechanism proposed in the first chapter to analyse the effect of a government spending shock on the external sector of the economy. First I use a VAR model estimated using US data to show that an increase in government spending, not only is associated to an increase in consumption and productivity, but also generates a depreciation of the real exchange rate. Under the assumption of complete market, the international risk sharing condition determines a strong correlation between domestic consumption and the real exchange rate. In a standard DSGE model the reduction in consumption necessarily leads to a counterfactual appreciation of the real exchange rate. I show that LBD provides a valid solution to make consumption and the real exchange rate move in the right direction.

In the third chapter, I study the effect of a government spending shock on housing market. The 2008 recession has registered a collapse in house

²Chang et al. (2002) show that LBD provides an additional propagation channel in a standard RBC. This thesis demonstrates that, in the presence of nominal rigidities, it has crucial *qualitative* implications for the response of consumption and many other variables to government expenditure shocks.

prices. Restoring a sound housing market seems to be a keystone through the economic recovery. Using US data, I first provide empirical evidence that an increase in government spending is associated to a boost in real house prices. In a model where housing can be used as collateral to borrow by credit constrained households, the increase in housing wealth introduce an additional propagation mechanism for a government spending shock. I present a model with two sectors, heterogeneity in the households' discount factor, and credit constrained agents that can use housing as collateral. I show that introducing the LBD mechanism described in the first chapter, makes the model able to replicate the observed response of real house prices, whereas the model without skills accumulation cannot account for the empirical findings. The collateral channel amplifies the response of consumption to a government shock. The model is estimated by matching VAR and DSGE impulses responses.

CHAPTER 1

Fiscal stimulus with Learning-By-Doing

1.1 Introduction

What are the effects of a change in government spending on the private sector of the economy? The question has been a central issue in the macroeconomic policy debate for a long time. The 2008 global recession has renewed interest and has fuel the research in this topics.

The empirical and theoretical literature has extensively investigated the effects of a government spending shock on domestic economic activity. Despite the effort, is still difficult to reconcile the evidences provided by the empirical literature with the result of a fully specified Dynamic Stochastic General Equilibrium (DSGE) model. Most of the empirical literature provides evidences that support some stylized facts: an exogenous increase in government spending leads to an increase in output, private consumption, productivity, hours worked and real wages.

The DSGE literature has not yet found a shared solution to account for all these empirical findings, and therefore has failed to provide insights into the key propagation mechanism of a government spending shock.

In this chapter I propose a mechanism based on an endogenous increase in total factor productivity trigger out by a positive government spending shock. This chapter shows how introducing a Learning-by-Doing (LBD) mechanism à la Chang et al. (2002) in an otherwise standard DSGE model featuring nominal rigidities, generates a response of consumption that is consistent with the empirical evidences.

As in Chang et al. (2002) the level of output produced depends on the workers' skills with the latter evolving according to a LBD mechanism, so that past work experience affects the current level of skills. In contrast with the standard model, a positive government spending shock produces an increase in consumption.

This result stems from the fact that in my model the increase in government spending leads to an endogenous increase in total factor productivity. In fact, even if spending is completely wasteful, a positive government shock increases the level of hours worked. By the LBD mechanism, the increase in hours results in a higher level of skills in the following periods. Since standard accounting techniques ignore workers' skills, a change in the level of skills would be considered an increase in total factor productivity.

If the increase in productivity is large enough, marginal costs fall and cause a reduction in the expected path of inflation. In the attempt to stabilize the price level, the central bank cuts the nominal interest rate more than inflation. The resulting decline in the long term real interest rate increases consumption. I also show that nominal rigidities play a crucial role in determining these results.

The remainder of this chapter is organized as follow. Section 1.2 presents an empirical and theoretical literature review. Section 1.3 presents a DSGE model with LBD. Section 1.4 uses a simplified model to illustrate the mechanism through which LBD affects the propagation mechanism of a government spending shock. Section 1.5 presents the econometric approach and discusses the simulation results for the complete model. Section 1.6 concludes.

1.2 Literature review

In this section I propose a brief literature review on the effects of a government spending shock. I start from empirical evidences and then I turn to the results provided by theoretical models.¹

¹For a more comprehensive and extended literature review see Hebous (2011)

1.2.1 Empirical literature

Researchers have largely employed Vector autoregression (VAR) models to study the effect of a change in government spending. One of the most challenging task is the correct identification of structural shocks. This aim has been accomplished in the literature by four different methods: the recursive approach, the structural identification approach, the narrative approach and the sign restriction approach.

First of all, consider that a structural VAR model can be written as:

$$AZ_t = \sum_{j=1}^p B_j Z_{t-j} + \varepsilon_t \quad (1.1)$$

where Z_t is a vector of observable variables, p is the chosen lag length and ε_t is a vector of structural shocks. A and B_j are matrix of coefficients. In order to recover structural shocks, restrictions have to be imposed on the matrices A and B . Each approach is based on a different identification strategy and imposes a different set of restrictions on the two matrices.

In the recursive approach the first variable is assumed to respond only to its own exogenous shock. Thus, with the recursive approach the identification of a structural government spending shock is reached by ordering government spending first. Under this assumption, the residual from a regression of government spending on its own lag and on the lags of all other variables can be interpreted as structural government spending shocks. This assumption implies that government spending is allowed to respond to other variables included in the VAR model only with one lag.

The structural identification approach imposes the identification restrictions using external information in order to estimate the elasticity of the government variables of interest to other variables in the VAR. This identification scheme, which is mainly employed when also a tax shock is considered, produce results similar to those obtained using the recursive approach.

The narrative approach includes in the VAR a dummy variable (so that this approach is also defined dummy variable approach) that captures date of exogenous increase in government spending such as war events. Ramey

(2011b) shows that the narrative approach performs better in capturing the anticipated effects of a policy change. In fact, she shows that shifting forward the original event dates enables the narrative approach to reproduce results in line with the structural identification or recursive approaches. However, as noted in Perotti (2008) the dummy variable approach has different drawbacks. First this approach ignores the role that other shocks can have during the chosen event date. Second, it assumes that the dynamic of fiscal variables is the same across all the episodes, and therefore it does not consider that each episode can be characterized by different fiscal instruments mix.

Differently from the previous approaches, the sign restriction approach does not impose any restriction on the matrices of the VAR model but instead imposes restrictions on the sign of impulse responses. The main issue is how to correctly impose the restrictions required to identify a government spending shock.

The correct identification of a government spending shock is not trivial and, as noted before, each method presents its drawbacks. The choice of identification strategy is also complicated by the fact that the different approaches discussed above can lead to different results, not only regarding the size but also the qualitative effects of government spending on macroeconomic variables. In what follow I try to provide a very general review of the effect of a government spending shock on several variables.

Output. The response of output to a government spending shock is in general found positive, regardless of identification assumption used. However, the quantitative effect can be significantly different. Ramey (2011a) concludes that the fiscal multiplier for the US ranges from 0.8 to 1.5. The size of fiscal multipliers can be affected by several elements. Auerbach and Gorodnichenko (2012) demonstrate the magnitude of the multiplier is affected by economic conditions and that there exists significant non-linear effects. They found that during recessions the multiplier is considerably larger than expansion periods. They also show that each components of spending deliver different multipliers. The size of the multiplier also seems to change over time. Perotti (2005) finds that in the US only for the sub-sample pre-1980 the government spending multiplier is larger than one.

Consumption. The response of private consumption to a government spending shock is not unique and depends on the identification strategy applied. The recursive and the structural identification assumptions deliver a significant, persistent and hump-shaped increase in consumption (see among many others Fatás and Mihov (2001), Blanchard and Perotti (2002), and Galí et al. (2007)). Results obtained from sign restriction are more ambiguous. For example, Mountford and Uhlig (2009) find an insignificant, small and short-lived increase in consumption. Ramey and Shapiro (1998) and Edelberg et al. (1999) using a narrative approach based on military build-ups, find evidences of a fall in consumption. Ramey (2011b) using a revised series of government spending shocks based on Ramey and Shapiro (1998) concludes that while durable and non-durable goods consumption decreases, services consumption increases. Caldara and Kamps (2008) show that, controlling for differences in the specification of reduced-form models, private consumption significantly increase after a government spending shock, regardless of identification approach employed.²

Hours. The increase in hours worked after a government spending shock is a quite robust result. Evidences supporting the increase in hours worked have been found in Fatás and Mihov (2001), Ramey and Shapiro (1998), Burnside et al. (2004). Monacelli et al. (2010) document an increase in hours worked both on the extensive and on the intensive margin, although the increase in hours worked for employed person is not statistically significant.

Interest rate and inflation. Evidences of a drop of interest rates and inflation have been found in Fatás and Mihov (2001), Perotti (2005), Favero and Giavazzi (2007), Mountford and Uhlig (2009), Ramey (2011b) and Corsetti et al. (2012). These results do not seem to depend on the identification strategy used neither on the measure of interest rate and inflation chosen. However, the dynamic of inflation and interest rates responses to a government spending increase varies across studies. In fact, while some studies find an initial increase in the two variables followed by a steady fall below their pre-

²Recently the empirical literature has started to use microeconomic techniques to investigate the effects of a government spending shock. For, example, Giavazzi and McMahon (2012) using household-level data show that the response of consumption exhibits a high level of heterogeneity among households.

shock periods level, other studies provide evidences supporting the opposite dynamic.

Productivity. Early work by Evans (1992) finds a positive correlation between government spending and Solow residuals. Ramey and Shapiro (1998) show that an increase in military government spending raises labour productivity. Bachmann and Sims (2012) use a VAR approach to document the increase in TFP and to show that the increase is larger during recession. Nekarda and Ramey (2011) show a positive response of productivity to a government spending shock, although only at aggregate level and not at industry level.

1.2.2 Theoretical literature

In the previous part I have shown that most of the empirical literature provide evidences supporting the crowding-in effect of private consumption after a government spending shock. The aim of this section is to briefly discuss the predictions of standard DSGE models and provide an overview of the solutions proposed to improve the ability of theoretical models to produce results in line with the empirical literature evidences.

The classical nomenclature employed in the literature distinguishes between Real Business Cycle and New Keynesian DSGE models. The main difference is that the former class of model does not include nominal frictions. However, although the magnitude can be different, the effects of a change in government spending in a standard version of both models are qualitatively very similar. The main difference is that, at least under some circumstances, NK models and RBC models predict a response of real wages of different sign.

Baxter and King (1993) provide useful insights to understand the key propagation mechanism of a government spending shock. The government budget constraint requires that an increase in government spending have to be associated with an equivalent increase in taxes present value. An infinitely lived, rational and forward looking representative agent understands that an increase in government spending implies an increase in tax liabilities burden which will reduce his available wealth. In this economy the Ricardian equivalence holds and consumers react to this negative wealth effect by reducing both

consumption and leisure. Despite the increase in hours worked, the burst in output is not sufficient to meet the increased aggregate demand related to the increase in government spending. Hence interest rate have to rise to induce a decline in consumption and other components of gross domestic product to make up for the difference.

In a NK model the mechanism is similar. However, the presence of nominal rigidities have important effects on the labour market. Since firms cannot change their prices, they are willing to increase the desired level of goods supply. Therefore, the presence of nominal frictions leads to an increase in labour demand larger than in the RBC models. If the increase in labour demand is sufficiently high real wages increase. As real wage rises, households work harder and substitute consumption for leisure. However, this intra-temporal effect is dumped by a stronger inter-temporal effects. The increase in wages causes an increase in marginal costs and in the expected path of inflation. A standard Taylor rule prescribes, in the attempt to stabilize inflation, to increase nominal interest rate more than inflation, causing a raise in the long-term real interest rate and hence a fall in the current level of consumption.

Both NK and RBC models therefore predict a counter-factual decrease in consumption. The literature has proposed different solutions in order to bring the simulated responses of DSGE models closer to the empirical evidences.

Because virtually all DSGE models predict an increase of hours worked, a proposed solution is based on assuming the non-separability between consumption and leisure. Linnemann (2006) show that if the degree of complementarity is strong enough a non-additively separable utility function can deliver the increase in consumption found in the data. However, as noted in Bilbiie (2009), these results can be achieved only if either consumption or leisure are inferior goods. Whereas, Monacelli and Perotti (2008) show that the form of non separability proposed in Greenwood et al. (1988) can be successful in matching the empirical response of private consumption.

The deep-habit mechanism introduced in Ravn et al. (2006) enables the model to capture the increase in consumption by generating counter-cyclical mark-ups. In their model, consumers form habit consumption on a good-by-good basis. Hence, the current level of demand faced by goods producers affects

their demand in the future. A government spending shock increases aggregate demand. In order to capture this increase and secure a higher level of sales in the future, in setting their prices, firms are willing to reduce their mark-up and increase their output and labour demand. As result of the increased level of labour demand, real wages increase, triggering a strong substitution effect from leisure into consumption which delivers a positive response of consumption to a government spending increase.

Galí et al. (2007) investigate the effect of incomplete asset market. In their model they distinguish between Ricardian and rule-of-thumb consumers. The latter have no access to financial market and therefore consume all their disposal income. If the increase in government spending leads to a rise in real wages, non-Ricardian agents increase consumption. If the share of these individuals in the economy is sufficiently large the effect on aggregate consumption can be positive since the decline in the level of consumption of Ricardian agents is more than offset by the increase of consumption of non-Ricardian agents.

Corsetti et al. (2012) analyse the effect of an endogenous and systematic adjustment of government spending to public debt. This spending reversal mechanism implies that a deficit financed increase in government spending is expected to bring a reduction in the government spending level in the future and hence in the aggregate level of demand and in the expected path of inflation. The resulting fall in long-term real interest rate causes an immediate increase in consumption.

The literature has also analysed the impact of government spending on total factor productivity within the framework of general equilibrium models.

Baxter and King (1993) show that if government spending is productive the growth in resources available in the future leads to an increase in consumption. Within the same framework Glomm and Ravikumar (1997) consider the effect of government spending on education. Linnemann and Schabert (2006) extend the analysis to a New Keynesian model. However, these papers require government spending to enter in the production function directly and fail to explain the observed increase in TFP when government spending is entirely wasteful.

By contrast, Devereux et al. (1996) develop a model where TFP endo-

genously increases after a government spending shock, independently of the government spending composition. In their model the increase in total factor productivity derives from the presence of increasing return to specialization coupled with a free-entry condition that generate a pro-cyclical variation in the number of intermediate firms. However, their model has the counter-intuitive implication of generating an upward sloping labour demand.

1.3 The model

In this section I present a new-Keynesian DSGE model including LBD. The model is based on Smets and Wouters (2007) and incorporate the LBD mechanism proposed in Chang et al. (2002).

Intermediate goods firms are monopolistic competitors that produce intermediate goods using labour and capital as input. The level of workers' skills depend on the hours worked in the previous period. Final goods producers aggregate intermediate goods to obtain an homogeneous goods that can be used for private and public consumption and investment. Households consume and provide labour and capital services to intermediate firms. Nominal frictions imply prices and wages can adjust only infrequently.

1.3.1 Final goods producers

The final goods producer is a perfect competitive firm that aggregates a continuum of intermediate goods $Y(j)$ to obtain a final good Y_t using the following aggregation technology:

$$Y_t = \left[\int_0^1 Y_t(j)^{\frac{1}{1+\lambda_f}} dj \right]^{1+\lambda_f} \quad (1.2)$$

where λ_f is a positive parameter that depends on price elasticity and determines the level of price mark-up.

Final good is sold to households and government and can be used for both consumption and investment. Combing first order conditions for the final producer maximization profit problem with the zero profit condition yields

the following demand for intermediate goods:

$$Y_t(j) = \left(\frac{P_t(j)}{P_t} \right)^{-\frac{1+\lambda_f}{\lambda_f}} Y_t \quad (1.3)$$

where $P_t = \left[\int_0^1 P_t(j)^{-\frac{1}{\lambda_f}} dj \right]^{-\lambda_f}$ is the aggregate price index for the final good and $P_t(j)$ is the price of the intermediate good of type j .

1.3.2 Intermediate goods producers

Intermediate goods producers are monopolistic competitors in their product market. The intermediate good j is produced using the technology:

$$Y(j) = A_t (K_t(j))^\alpha (N_t(j)X_t)^{(1-\alpha)} \quad (1.4)$$

where $0 < \alpha < 1$, $K_t(j)$ and $N_t(j)$ denote the physical capital and the homogeneous labour services used to produce the j^{th} good. A_t is a productivity shock that evolves according to:

$$\ln A_t = (1 - \rho_a) \ln A + \rho_a \ln A_{t-1} + \varepsilon_t^a \quad (1.5)$$

where $\varepsilon_t^a \sim (0, \sigma_a^2)$.

X_t denotes the average level of skills of labour suppliers which depends on total hours worked in the past. Following Chang et al. (2002), skill accumulation is assumed to evolve according to:

$$X_t = X_{t-1}^{\rho_x} N_{t-1}^{\mu_n} \quad (1.6)$$

where $0 < \rho_x < 1$ and $\mu_n \geq 0$.

This formulation of LBD assumes that workers and firms perceive skill accumulation as external. In this sense the definition of LBD employed in the present thesis is akin to the LBD mechanism included in Arrow (1962). LBD is a side effect of production and does not require any decision about the amount of time or resources to allocate to human capital accumulation.

Cooper and Johri (2002) consider an alternative formulation in which the

accumulation of what they call organizational capital is internal to firms and results from purposeful investment. In response to a positive aggregate demand shock, firms have an additional incentive to increase hours worked in their organization to benefit from a higher level of firm-specific productivity.

The mechanism introduced in Cooper and Johri (2002) is likely to produce results similar to the deep habit model in Ravn et al. (2006) described earlier. Consider for example a government expenditure increase. In order to attain a higher level of productivity, firms try to increment hours worked in their organization. It follows a larger shift in the labour demand which could lead to an increase in the real wage and eventually generate an intra-temporal substitution effect between leisure and consumption strong enough to offset the negative wealth effect related to the increase in taxes. The large shift in hours worked and the increased productivity could yield an increment in the level of output sufficiently large to meet the increase in government spending without crowding out private consumption.

The approach to LBD used in this thesis also generate a substitution effect similar to the one generated by introducing deep habit in consumption. The increase in productivity leads to an increase in real wages that incentives household to substitute consumption for leisure. However, as I show in section 1.4.2, this intra-temporal effect is not sufficiently strong to yield an increase in private consumption. Nominal frictions, absent in Ravn et al. (2006), play a crucial role in determining the increase in private consumption in response to an increase in government expenditure.

As noted in Chang et al. (2002), the fact that skills are embodied in workers offers several advantages. In particular, because the benefits of LBD are included in workers' wages, it make easier to use macroeconomic variables to measure the effect of LBD and estimate the model. The model proposed in Cooper and Johri (2002) would require observations at plant level to estimate the parameters controlling the organizational capital accumulation process.

Moreover, introducing LBD as pure externality to both firms and households has the advantage of making the model easily tractable and represents the simplest way to model a LBD mechanism that is able to capture the endogenous change in the level of productivity through the effect of past hours

worked. I leave the analysis of the effects and implications of the internalization of LBD as areas of further research.

The nominal wage W_t and the rental cost of capital R_t^K are given for the intermediate goods producers. Hence, cost minimization implies the same capital-to-labour ratio for all firms

$$\frac{K_t}{N_t} = \frac{\alpha}{1-\alpha} \frac{W_t}{R_t^K} \quad (1.7)$$

The marginal cost, common to all firms, is:

$$MC_t = \frac{W_t^{(1-\alpha)} R_t^{K\alpha}}{\alpha^\alpha (1-\alpha)^{(1-\alpha)} X_t^{(1-\alpha)} A_t} \quad (1.8)$$

Following Calvo (1983) I assume that in every period a fraction of firms ζ_p cannot re-optimize their prices $P_t(j)$. In this case firms adjust their prices mechanically according to the rule:

$$P_t(j) = (\pi_{t-1})^{\iota_p} (\pi)^{1-\iota_p} \quad (1.9)$$

where $\pi_t = P_t/P_{t-1}$ and π is the steady-state inflation rate.

The fraction $(1 - \zeta_p)$ of firms able to re-optimize their price chose the new price to solve:

$$\max_{P_t(j)^{new}} \mathbb{E}_t \left[\sum_{s=0}^{\infty} (\zeta_p \beta)^s \Xi_{t+s} \left(P(j)^{new} \left(\prod_{l=1}^s (\pi_{t-1+l})^{\iota_p} (\pi)^{1-\iota_p} \right) - MC_{t+s} \right) Y_{t+s}(j) \right] \quad (1.10)$$

subject to the demand function (1.3). The term $\beta^s \Xi_{t+s}$ is the current value of a future dollar expressed in consumption units.

Considering only a symmetric equilibrium where all firms choose the same price, the law of motion for the aggregate price is:

$$P_t = \left[(1 - \zeta_p) (P_t^{new})^{-\frac{1}{\lambda_f}} + \zeta_p ((\pi_{t-1})^{\iota_p} (\pi)^{1-\iota_p} P_{t-1})^{-\frac{1}{\lambda_f}} \right]^{\lambda_f} \quad (1.11)$$

1.3.3 Households

The objective function for the households $i \in [0, 1]$ is given by:

$$\mathbb{E}_t \sum_{s=0}^{\infty} \beta^s \left\{ \log (C_{t+s}(i) - h C_{t+s-1}(i)) - \frac{N_{t+s}^{1+\varphi}(i)}{1+\varphi} \right\} \quad (1.12)$$

where $C_t(i)$ is consumption, $N_t(i)$ denotes the quantity of the i^{th} type of labour service supplied; h measures household's habit persistence in consumption and $\varphi > 0$ is the inverse of labour supply elasticity.

The household's budget constraint is:

$$\begin{aligned} P_{t+s} C_{t+s}(i) + P_{t+s} I_{t+s}(i) + B_{t+s}(i) &\leq R_{t+s-1} B_{t+s-1}(i) + W_{t+s}(i) N_{t+s}(i) \\ &+ [R_{t+s}^K u_{t+s}(i) - P_{t+s} a(u_{t+s}(i))] \bar{K}_{t+s-1}(i) + \Pi_{t+s}(i) - T_{t+s}(i) \end{aligned} \quad (1.13)$$

The right-hand side of the expression (1.13) corresponds to the household income net of the lump-sum taxes (or transfers) $T_t(i)$. Total income consists of different components. The net cash inflow from holding a one-period government bond is denoted by $R_t B_t(i)$. Labour income is $W_t(i) N_t(i)$. The term $[R_t^K u_t(i) - P_t a(u_t(i))] \bar{K}_{t-1}(i)$ indicates the income from renting physical capital to intermediate firms. Following Smets and Wouters (2003) the effective capital rent to intermediate goods producer firms is $K_t(i) = u_t(i) \bar{K}_{t-1}(i)$, where $u_t(i)$ is the utilization rate of installed capital chosen by households. Households receive R_t^K for each unit of capital service supplied. However, they must pay a cost of utilization $a(u_t(i))$, expressed in term of the consumption good. As Christiano et al. (2005) I assume $u = 1$, $a(1) = 0$ and $a''(1) > 0$. Households also receive dividends Π_t from the imperfect competitive intermediate firms. Income can be used for consumption $C_t(i)$ and investment in both physical capital $I_t(i)$ and government bond $B_t(i)$.

As in Christiano et al. (2005) the capital accumulation evolves according to:

$$\bar{K}_t(i) = (1 - \delta) \bar{K}_{t-1}(i) + \left[1 - S \left(\frac{I_t(i)}{I_{t-1}(i)} \right) \right] I_t(i) \quad (1.14)$$

where δ is the depreciation rate, and $S(\cdot)$ is the cost of adjusting investment

with $S(1) = S'(1) = 0$ and $S''(1) > 0$.

1.3.4 Labour contractors and wage setting

Each household is a monopolistic supplier of a differentiated labour service $N_t(i)$ to labour contractors. Labour contractors are perfect competitive firms. They aggregate the differentiated labour services into an homogeneous labour service N_t hired by intermediate goods producers. The aggregation function is:

$$N_t = \left[\int_0^1 N_t(i)^{\frac{1}{1+\lambda_w}} di \right]^{1+\lambda_w} \quad (1.15)$$

where $\lambda_w > 0$ is a fixed parameter.

Profit maximization for the labour contractors yields the i -type labour demand:

$$N_t(i) = \left(\frac{W_t(i)}{W_t} \right)^{-\frac{1+\lambda_w}{\lambda_w}} N_t \quad (1.16)$$

where $W_t = \left[\int_0^1 W_t(i)^{-\frac{1}{\lambda_w}} di \right]^{-\lambda_w}$.

Households face *à la* Calvo-style wage setting frictions. In each period the fraction ζ_w of households are unable to readjust their wage. In this case households set their wage according to:

$$W_t(i) = (\pi_{t-1})^{\iota_w} (\pi)^{1-\iota_w} W_{t-1}(i) \quad (1.17)$$

Those households able to re-optimize their wage solve:

$$\max_{W_t^{new}} \mathbb{E}_t \sum_{s=0}^{\infty} \zeta_w^s \beta^s \left\{ -\frac{(N_{t+s}(i))^{1+\varphi}}{1+\varphi} \right\} \quad (1.18)$$

subject to (1.13), (1.16) and

$$W_{t+s}(i) = \prod_{l=1}^s (\pi)^{(1-\iota_w)} (\pi_{t+l-1})^{\iota_w} W_t^{new} \quad (1.19)$$

Considering a symmetric equilibrium in which all households able to set a new wage chose the same level, wage evolution is defined as:

$$W_t = \left\{ (1 - \zeta_w) (W_t^{new})^{-\frac{1}{\lambda_w}} + \zeta_w \left[(\pi)^{(1-i_w)} (\pi_{t-1})^{i_w} W_{t-1} \right]^{-\frac{1}{\lambda_w}} \right\}^{-\lambda_w} \quad (1.20)$$

1.3.5 Government policies

The central bank sets the nominal interest rate R_t according to a Taylor rule that responds to inflation and GDP growth:

$$\frac{R_t}{R} = \left(\frac{R_{t-1}}{R} \right)^{\rho_r} \left[\left(\frac{\pi_t}{\pi} \right)^{\phi_\pi} \left(\left(\frac{GDP_t}{GDP_{t-1}} \right)^{\phi_{gdp}} \right) \right]^{(1-\rho_r)} \exp(\varepsilon_t^r) \quad (1.21)$$

where variables without time subscript denote steady state values. ε_t^r is an independently and identically distributed monetary shock with standard deviation σ_r . Following Christiano et al. (2010), GDP_t denotes real per capita GDP and it is defined as:

$$GDP_t = C_t + I_t + G_t \quad (1.22)$$

Government spending is financed either by issuing a bond or by a lump-sum tax. Therefore, the government budget constraint is:

$$P_t G_t + R_{t-1} B_{t-1} = P_t T_t + B_t \quad (1.23)$$

Government sets the lump-sum tax following a simple feedback rule in order to prevent an explosive government debt.³

³As shown in Leeper (1991) the interaction between monetary and fiscal policy leads to two stable solutions where one policy is “active” and the other one is “passive”. Fiscal policy is passive when government takes monetary rule as given and passively adjusts taxes to balance the budget constraint. If the change in taxes is not sufficiently large to bring debt back to its target level, fiscal policy is defined as active. Monetary policy is active when monetary authority pursues its inflation target by strongly responding to inflation. Whereas, monetary policy is passive when is constrained to balance the government budget constraint. In this case, debt becomes sustainable only through changes in the level of real interest rate.

Following the basic assumption of the mainstream DSGE models, I only consider the

Finally, government spending is defined by:

$$\ln G_t = (1 - \rho_g) \ln G + \rho_g \ln G_{t-1} + \varepsilon_t^g \quad (1.24)$$

where $\varepsilon_t^g \sim (0, \sigma_g^2)$.

Following most of the DSGE literature, in the model proposed in this thesis government spending is an exogenous process and does not enter into the production function. The effects of government spending on productivity occurs only indirectly through the LBD mechanism.

In order to account for the observed effect of government spending on productivity, the literature has explored alternative modelling choices. Baxter and King (1993) and Pappa (2009) introduce government spending into the production function. While these models can successfully account for the increase in productivity and generate a positive response of consumption, the empirical relevance of this mechanism is open to question. For example, while Aschauer (1989) find the elasticity of output with respect to public capital to be 0.24 for core infrastructures, Evans and Karras (1994) and Kamps (2004) find that in many case public capital has no effect or even a negative effect on output. Furthermore, Leeper, Walker and Yang (2010) show that implementation delays to build public capital and the mix of tax instruments can interfere with the effects of the government investment expenditure and eventually revert the positive effect on private consumption.

In search of mechanisms that can account for the increase in productivity associated to a government expenditure boost, Glomm and Ravikumar (1997) consider skills accumulation through education. However, as noted in Chang et al. (2002), most education takes place in several years. Therefore, while

case of active monetary policy and passive fiscal policy. The monetary rule specified in (1.21) ensures the monetary authority actively pursues price stability provided that ϕ_π is sufficiently large. On the other hand, fiscal policy authority passively adjusts lump sum taxes to balance the budget constraint (1.23). Since in the model presented in this chapter Ricardian equivalence holds, including a tax rule for lump sum taxes and the evolution of government debt in the set of equations that define the model equilibrium would be redundant. In fact, in this model the distribution of taxes across time is irrelevant and neither affects the decisions of agents nor alters the dynamics of economy.

government spending in education would be successful in explaining long-run growth in productivity, it would be hard to explain short run fluctuation in the level of skills by appealing to this mechanism.

1.3.6 Goods market clearing

Aggregating the budget constraint (1.13) across households and combining with the government budget constraint (1.23) yields the goods market clearing condition:

$$Y_t = C_t + I_t + a(u_t) \bar{K}_{t-1} + G_t \quad (1.25)$$

Equation (1.25) states that final output is absorbed by private consumption, investment and government spending. In addition, a part of final output is used to cover the capital utilization cost.

1.4 How LBD works? A simplified model

Before turning to model simulation, in this section I illustrate the mechanisms through which introducing LBD can bring the responses of consumption and TFP to a government spending shock closer in line with the data. To illustrate this mechanism I consider a simplified version of the model presented in section 1.3.

1.4.1 Parameterization

This section illustrates the parameter values employed for the simulation of the simplified model. In what follows I consider a log-linearized approximation of the model around the deterministic steady state in which inflation is zero. The model is solved using the algorithm proposed in Ireland (2004). Each period corresponds to a quarter. The responses of the nominal interest rate and inflation are measured as annualized percentage points deviation from the steady state level. The remaining variables are expressed in quarterly

percentage deviation from the steady state levels. Where appropriate, variables are measured in real terms. In what follows ‘ $\hat{\cdot}$ ’ denotes variables expressed in log-deviation from steady state.

The simplified model differs from the model presented in section 1.3 in the following ways. First, there is no capital dynamic and intermediate goods producers have a linear production function ($\alpha = 0$ in equation (1.4)). Consumption habit formation is switched off ($h = 0$). I exclude wages and prices indexation to past inflation ($\iota_w = \iota_p = 0$). I assume monetary authority targets only current inflation ($\rho_r = \phi_{gdp} = 0$). To simplify the algebra and without loss of generality I set the inverse of Frisch elasticity φ equal to 1. The discount factor β is equal to 0.9925 and corresponds to a steady state nominal interest of around 3% per year. λ_f and λ_w are both set equal to 0.05 implying that price and wage mark-ups in steady state are equal to 5%. I set $\zeta_p = 0.75$ and $\zeta_w = 0.83$ implying firms can change price on average once a year and that the average wage duration is almost six quarters. The two parameters for the Learning-By-Doing, μ_n and ρ_x , are taken from Chang et al. (2002) and are equal to 0.111 and 0.798. The autocorrelation coefficient for the government spending ρ_g is set to 0.90 as in Galí et al. (2007). The steady-state share of government spending is assumed to be 0.20 corresponding to the post-war period average. I focus on the effects of a positive government spending shock and I neglect all remaining shocks.

1.4.2 Simulation results

In this simplified model, the optimal households behaviour yields the standard Euler equation:

$$\hat{c}_t = \mathbb{E}_t [\hat{c}_{t+1}] - (\hat{r}_t - \mathbb{E}_t [\hat{\pi}_{t+1}]) \quad (1.26)$$

Whereas, from firms first order conditions is possible to derive the New Keynesian Phillips Curve (NKPC):

$$\hat{\pi}_t = \beta \mathbb{E}_t [\hat{\pi}_{t+1}] + \frac{(1 - \zeta_p)(1 - \beta \zeta_p)}{\zeta_p} \hat{mc}_t \quad (1.27)$$

where the real marginal cost is a function of the real wage and the stock of

knowledge

$$\widehat{mc}_t = \widehat{w}_t - \widehat{x}_t \quad (1.28)$$

Integrating forward equations (1.26) and (1.27) yields:

$$\widehat{c}_t = -\mathbb{E}_t \sum_{s=0}^{\infty} (\widehat{r}_{t+s} - \widehat{\pi}_{t+1+s}) \quad (1.29)$$

$$\widehat{\pi}_t = \frac{(1 - \zeta_p)(1 - \beta\zeta_p)}{\zeta_p} \mathbb{E}_t \sum_{s=0}^{\infty} \beta^s [\widehat{mc}_{t+s}] \quad (1.30)$$

Equation (1.29) states that current consumption is negatively related to the sum of current and future short-term real interest rates. Note that, up to a first order approximation, this sum is equal to the real rate of return on a bond of infinite duration. Thus, the consumption dynamics is driven by the inter-temporal effect working through the real interest rate. A positive government shock can increase consumption only if it reduces the long-term real rate. However, if monetary policy follows a Taylor rule the reduction can occur only if inflation falls below the steady state level. By equation (1.30) current inflation depends on the discounted sum of marginal costs which in turn are a function of the relative size of real wages and the stock of knowledge.

Figure 1.1 shows impulse responses for the simplified model with LBD (black solid line) and without LBD (red dashed line).

An increase in government spending triggers out both intra-temporal and inter-temporal effects. Because of price frictions, output is demand-driven. As a result of the positive price mark-up, those firms that cannot change price increase production and labour demand to meet the rise in aggregate demand caused by the government's fiscal policy stance. Yet, for the government budget constraint to hold, the increase in government spending is associated with an increment in households tax burden which in turn reduces the resources available in the future for the private sector. The negative wealth effect leads agents to *feel* poorer, and to the extent leisure and consumption are normal goods, they reduce both of them causing an outward shift in labour supply.

Both with and without LBD the new equilibrium in the labour market is associated to an increase in hours and real wages. As the real wage rises, households increase labour supply and substitute consumption for leisure. Without LBD, though, this intra-temporal substitution effect is not strong enough to compensate for the negative wealth effect associated with the increase in future taxes required for the government budget constraint to hold. Furthermore, in absence of LBD, the increase in the real wage raises marginal costs. The fraction of firms able to re-optimize their price will respond to the increase in marginal costs by setting a higher price. The gradual increase in the price level raises the expected path of inflation, to which the monetary authority reacts by sharply increasing the nominal interest rate. This translates into an increase in the real interest rate which, by equation (1.29), brings about an inter-temporal effect that induces households to *reduce* consumption.

With LBD, instead, the increase in hours worked triggers an increase in the skill level. The negative wealth effect is milder because the increase in future labour productivity raises resources available in the future. Because of the higher increase in the real wage the intra-temporal substitution effect between consumption and leisure is stronger. Furthermore, the LBD mechanism more than offsets the inter-temporal substitution effect. With LBD, marginal costs increase for a few periods but then fall below the steady state level. This results in a fall in inflation and the real interest rate. The lower real interest rate reduces the return to saving and induces agents to increase current consumption. Thus, the combination of intra and inter-temporal effects, based on the increase in productivity generated by the LBD mechanism, offset the negative wealth effect and the final result is an increase in consumption.

Consider now the effect of the increased level of skill on labour market and the role played by nominal rigidities.

First, note that firms with some market power set their prices applying a mark-up over the marginal costs. The presence of price stickiness generates an endogenously variable mark-up. Hence, considering a symmetric equilibrium gives:

$$P_t = \mu_t^P MC_t \quad (1.31)$$

where μ_t^P is the time-varying price mark-up.

Denoting the real wage by \tilde{W}_t and substituting out for real marginal costs using (1.31), the representative intermediate firm's first order condition for labour demand can be written as:

$$\tilde{W}_t = \frac{MPL_t}{\mu_t^P} \quad (1.32)$$

where MPL_t denotes the marginal product of labour.

Given the absence of capital in production, the marginal product of labour coincides with the skill level and is constant in the absence of LBD.

The existence of price rigidities introduces a variable wedge between the real wage and the marginal product of labour. Similarly, the presence of wage frictions generates a non constant wedge between the wage and the intra-temporal marginal rate of substitution between leisure and consumption:

$$\tilde{W}_t = \mu_t^W MRS_t^{C,N} \quad (1.33)$$

where $MRS_t^{C,N}$ denotes the marginal rate of substitution and μ_t^w is the time-varying wage mark-up.

By log-linearizing equations (1.32) and (1.33) the labour demand and the labour supply can be written as:

$$\widehat{w}_t = \widehat{mpl}_t - \widehat{\mu}_t^p \quad (1.34)$$

$$\widehat{w}_t = \widehat{mrs}_t + \widehat{\mu}_t^w \quad (1.35)$$

Combining the last two equations, and using the definition of intra-temporal marginal rate of substitution, yields the labour market equilibrium condition:

$$\widehat{mpl}_t = \widehat{\mu}_t + \widehat{n}_t + \widehat{c}_t \quad (1.36)$$

where $\widehat{\mu}_t \equiv \widehat{\mu}_t^w + \widehat{\mu}_t^p$. The labour market equilibrium condition (1.36) allows to highlight an important result. Given the increase in hours, consumption can rise only if the marginal product increases or the sum of wage and price

mark-ups falls.

Figure 1.2 shows a graphical representation of the labour market described by equations (1.34)-(1.36) for the model with LBD (black solid line) and without LBD (red dashed line). Figure 1.2.A plots the equilibrium response of the labour market variables and figure 1.2.B plots labour demand and supply.

As shown in figure 1.2.B both for the model with and without LBD the labour market is in steady state at the point E_{SS} where the labour demand is LD_{SS} and the labour supply is LS_{SS} . As discussed above, the government shock produces an upward shift in the labour demand and a outward shift in the labour supply. Thus, the labour demand and the labour supply move respectively from LD_{SS} and LS_{SS} to LD_1 and LS_1 for the model without LBD and to LD_1^{LBD} and LS_1^{LBD} for the model with LBD. The different magnitude of these shifts depends on the responses of price and wage mark-ups. Since it takes one period to transform hours worked into new skills, at the time of the spending shock, the marginal product of labour is unaffected for both the model with and without LBD. However, the model with LBD displays a higher increase in the marginal rate of substitution between leisure and consumption due to the increase in the latter variable determined by the inter-temporal effect operating through the decrease in the long-term real interest rate. Thus, labour market equilibrium requires that the decline in the wage and the price mark-ups must be larger to make up for the difference (see equation (1.36)). These results are shown in figure 1.2.A. The larger fall in mark-ups and the increase in the marginal rate of substitution result in a larger shift in the labour demand and the labour supply for the model with LBD. The new equilibrium is E_1 for the model without LBD and E_1^{LBD} for the model with LBD. The latter equilibrium exhibits an higher level of hours and wage than the case without LBD.

Two periods after the shock, the labour supply starts to reverse to the pre-shock level both with and without LBD and shift respectively to LS_2 and LS_2^{LBD} . By contrast, the labour demand dynamics is completely different. For the model without LBD, as shown in figure 1.2.A, the marginal product of labour is unchanged, and there is little variation in the price mark-up. These facts are stylized by assuming $LD_2 = LD_1$. At the new equilibrium in E_2

hours are lower than the previous period and wage is constant. In the model with LBD the increase in marginal product of labour shifts the labour demand up to LD_2^{LBD} and the resulting equilibrium is in E_2^{LBD} .

Note that, because the knowledge accumulation depends only on the past hours worked, the labour demand slope is unchanged. Thus, differently from Devereux et al. (1996), the introduction of LBD does not generate an upward sloping labour demand.

Summing up, with LBD, the marginal product of labour increase and the initial decrease in wage and price mark-ups is larger. Around quarter 5 the total gap $\hat{\mu}_t$ turns positive and the marginal productivity, after reaching its peak, slowly decreases bringing a fall in consumption (see figure 1.1).

I now disentangle the contribution of LBD and nominal rigidities in determining the results of the model. As previously discussed, in the model without LBD the marginal product of labour is constant and the fall in the mark-ups is not sufficient to compensate the increase in hours worked and hence, by equation (1.36), consumption falls.

By contrast, figure 1.3 explores the consequences of government spending in a model that incorporates the LBD mechanism but with prices and wages fully flexible. The black solid line shows the responses for the baseline case with nominal frictions and the red dashed line refers to model without nominal frictions.

In latter case the model cannot generate the consumption increase. Indeed, the fall in consumption is larger than in the model with nominal frictions but without LBD. To see this point, consider that when nominal frictions are absent there is no shift in the labour demand at the time of the increase in government spending because firm can immediately change their price and the marginal product of labour is constant. Furthermore, without wage frictions households are on their perfectly competitive labour supply, so that they are less willing to increase labour supply. Thus, the new equilibrium in the labour market is determined by the labour supply shift along the labour demand and yields a lower increase in hours. The smaller increase in hours determines a lower increase in output so that the decrease in consumption must be larger to compensate for the increase in government spending. In addition, the lim-

ited increase in hours worked results in a lower future increase in the marginal product of labour, which in turns reduce the shift in the labour demand in the following period. Furthermore, with flexible prices, the increase in productivity cannot exert any deflationary effect. In fact, the increase in the productivity corresponds to an equivalent rise in the real wage and hence the key propagation mechanism proposed is switched off.

Finally, to see the effect of the degree of price stickiness consider equation (1.31) and assume that prices are extremely rigid ($\zeta_p \rightarrow 1$). In this case the increase in price mark-up $\hat{\mu}_t^p$ must be large enough to compensate for the decrease in marginal cost associated to the model with LBD. From equation (1.36) this has a negative effect on consumption. For a lower degree of price stickiness the increase in price mark-up is smaller and therefore enhances the possibility of a consumption's increase.

The reverse occurs for the degree of wage rigidity. In this case if wage are extremely rigid, ($\zeta_w \rightarrow 1$), given the increase in marginal rate of substitution, the decrease in the wage mark-up $\hat{\mu}_t^w$ must be large, and hence, by equation (1.36), there is a positive effect on consumption.

1.5 The complete medium size DSGE model

I now turn to the complete model presented in section 1.3. I first describe the econometric methodology employed and then I discuss the simulation results and the model properties.

1.5.1 Econometric methodology

In this section I describe the econometric strategy employed to estimate the model. The model is estimated using the two-step impulse responses matching procedure described in Altig, Christiano, Eichenbaum and Lindé (2011). I first describe the VAR step and then I provide details on the approach used to match the DSGE and the VAR impulse responses.

VAR step

I estimate the effect of three structural shocks on a set of variables. The three shocks considered are: a government spending, a monetary policy and a productivity shock. The structural VAR model is of the form:

$$AZ_t = c + \sum_{j=1}^p B_j Z_{t-j} + \varepsilon_t \quad (1.37)$$

where Z_t is a vector of observable variables, p is the lag length and ε_t is a vector of structural shocks. A and B_j are matrix of coefficients. My VAR model has 8 variables, which appear in this order: government spending, GDP per hours, inflation, GDP, government debt, private consumption, wages, and nominal interest rate. Where appropriate, variables are expressed in logs of real per capital terms. The VAR includes four lags, a constant and a linear time trend. The sample runs from 1966:1 to 2006:4. The beginning of the sample is dictated by data availability, in particularly with regard to the data on government debt, while the end date falls before the 2008 recession. More details about the data are provided in the appendix to this chapter.

The identification strategy requires to impose restrictions on the contemporaneous relationships among the variables included in the VAR. I estimate the model recursively. Given the variables order described above the restrictions imposed are the following.

First, following Blanchard and Perotti (2002), I assume that government spending is predetermined within the quarter. Thus, the identification strategy implies that all the variables in Z_t react immediately to government spending shocks, whereas government spending is allowed to respond with one lag to structural innovations other than government spending.

Second, following Christiano et al. (2005) I assume that a monetary policy shock has no contemporaneous effect on any variable other than the nominal interest rate.

Finally, a shock to the output per hours ratio is used as a proxy for the productivity shock described in section 1.3. The identification strategy used implies that the productivity shock has a contemporaneous effect on all the

variables except for government spending.

Impulse response matching step

The estimated parameters are chosen to minimize the distance between the VAR-based impulse response functions to the three shocks considered and the corresponding DSGE response functions.⁴ The impact responses of the DSGE model are restricted to account for the restrictions imposed by the VAR estimation strategy.

Let ζ denote the set of model parameters to be estimated and let $\Psi(\zeta)$ denote the mapping from ζ to the model impulse response functions (i.e. the DSGE impulses responses obtained using the set of parameter included in ζ). Let $\hat{\Psi}$ be the corresponding impulses responses function obtained from the VAR estimates. I consider the first 20 elements of each response function included the contemporaneous responses. The estimator of ζ is the solution to:

$$\hat{\zeta} = \min_{\zeta} \left[\left(\Psi(\zeta) - \hat{\Psi} \right)' V^{-1} \left(\Psi(\zeta) - \hat{\Psi} \right) \right] \quad (1.38)$$

where V is a diagonal matrix with the sample variances of $\hat{\Psi}$ along the diagonal.⁵ The matrix V can be interpreted as a weighting matrix ensuring that more precise VAR impulse responses are given more weight. Standard errors are calculated using the delta function method approach described in Iacoviello

⁴I do not consider government debt in the set of variables to match. Including government debt would require the estimation of the parameters regulating the tax rule. As shown in section 1.3.5, including the evolution of government debt in the set of equations that define the model equilibrium would be redundant, therefore there is no need to artificially increase the number of parameters to estimate. However, government debt is still included in the VAR model in order to consider the debt dynamics that arises from the government spending increase and to take into account feedback from the debt level and consider the possible endogenous response to debt of other variables included in the VAR. For a discussion on this point see Favero and Giavazzi (2007).

⁵The minimum of the function above is calculated using the function `lsqnonlin` available in Matlab. I use the Matlab version R2012b. Since the minimization routine employed can only find a local minimum, I performed several searches as a robustness analysis. The results, reported in the appendix, show that the choice of the initial guess has no significant implications. I have also considered the effect of changing the number of periods to match. The estimates obtained were very similar to the ones I found for the baseline specification.

(2005).

I estimate the baseline model and a model where LBD is switched off by imposing $\mu_n = \rho_x = 0$.

1.5.2 Parameters set a priori

Few parameters are fixed in the estimation procedure. For the households preference parameters I choose conventional values and set the inverse of the elasticity of labour supply φ equal to 3. The discount factor β is equal to 0.995 and corresponds to a quarterly value of capital to output equal to 9.5. The capital depreciation rate δ is set to 0.025 to capture the investment-output ratio of 24%. I set $\alpha = 0.30$ to account for a labour share around 2/3. λ_f and λ_w are both set equal to 0.05 implying that price and wage mark-ups at steady state are equal to 5%. The steady-state share of government spending is assumed to be 0.20 corresponding to the post-war period average. Following Christiano et al. (2010) I exclude price indexation ($\iota_p = 0$). Finally, I set the capital utilization adjustment cost to $u'' = 0.01$ because when I tried to estimate this parameters my algorithm pushed that estimate close to zero.⁶ Table 1.1 summarise the set of parameters fixed a priori and the corresponding values.

1.5.3 Estimated parameters

Table 1.2 reports the estimated values and the corresponding standard errors. The parameters regulating the LBD mechanism μ_n and ρ_x are respectively equal to 0.54 and 0.60. Respect to the values found in Chang et al. (2002), my estimate implies an higher initial impact and a faster return to the steady state level. For the model with LBD, the degree of wage and price stickiness ζ_w and ζ_p are respectively equal to 0.60 and 0.66, corresponding to an average duration of 2.5 and 3 quarters. The response of nominal interest rate to inflation ϕ_π is

⁶The choice of a small parameter for the capital adjustment cost implies a relative small cost for households to vary capital utilization. The corresponding elasticity of the utilization rate is 3.25. The range of values reported in the literature is extremely large: for example Smets and Wouters (2007) estimate this elasticity to be around to 0.85, whereas Christiano et al. (2005) set the elasticity equal to 10.

equal to 1.84 whereas the response to GDP growth ϕ_{gdp} is 0.65. The interest rate smoothing is pretty high with ρ_r equal to 0.76. The remaining parameters are in line with the previous literature. The estimation of the model without LBD delivers a higher price stickiness ($\zeta_p = 0.91$) corresponding to an average price duration of 2 years and half. The nominal interest rate smoothing is larger than the model with LBD whereas monetary policy is less responsive to inflation and GDP growth. The model without LBD also yields a higher degree of habit in consumption and a larger wage indexation to past inflation. Finally, the persistence of the technology shock ρ_a is smaller in the model without LBD.

1.5.4 Impulse responses

I now turn to the simulation results for the complete model presented in section 1.3. To this end, figures 1.4-1.6 report the response to the three shocks for the baseline DSGE model together with the VAR impulse responses and 95% confidence intervals. Overall the model is pretty successful in capturing the main stylized facts emerging from the VAR model. Figure 1.4 shows that the model is able to capture the increase in consumption, productivity and real wage, and the fall of inflation and interest rate in response to an expansionary government spending shock. However, the model is disappointing with regard to the quantitative effect. In particular, the response of consumption is quite small in comparison to the VAR-based response.

The model performs better in matching the responses to a monetary policy shock. As reported in figure 1.5 the model impulse responses are in general within the confidence intervals and very close to the VAR point estimates.

Finally, figure 1.6 reports the responses to a technology shock. Overall, the model delivers responses consistent with the data. The main failure is the inability of the model to mimic the large initial increase of GDP.

It is useful to stress that including LBD in the model is crucial to deliver responses to a government spending shock in line with the VAR based ones.

As figure 1.7 shows, absent LBD, by contrast with the empirical evidences, a government spending increase would have no effect on productivity and at

the same time would cause a counter-factual decrease of private consumption and an increase in inflation and interest rate.

The role played by LBD in mimic the response of monetary and productivity shocks is more limited. Figures 1.8 and 1.9 show that introducing LBD in the model in some cases amplifies the effects, whereas qualitatively the results are in general unaffected. The main difference is the response of inflation to a monetary policy shock. The model with LBD provides a solution to the so called “price puzzle” related to the initial increase of inflation in response to a contractionary monetary policy shock.⁷

1.5.5 Model properties

Table 1.3 reports the present value multiplier of government spending on impact and after 4, 16 and 20 quarters. The size of government spending multipliers is calculated using the method proposed in Mountford and Uhlig (2009).⁸

The model with LBD generates a GDP multiplier on impact in line with the data, whereas the model without LBD delivers a multiplier below 1. For the following periods, the value of the multiplier generated by the model with LBD is larger than the one found in the data.

The baseline model, differently from the model where LBD is switched off, generates a positive consumption multiplier. However, its value is sensibly smaller than the corresponding value observed in the data over all the horizons considered.

Finally, I compare second moments of simulated models to the data to assess their capability of accounting for some of the facts regarding the behaviour

⁷The “price puzzle” arises from the fact that most of the VAR literature finds an immediate significant increase in the price level in response to a contractionary monetary shock. However, most monetary policy models cannot explain this fact. The label “price puzzle” was introduced by Eichenbaum (1992).

⁸The present value government spending multiplier at horizon k (PV_k) for each variable

is calculated using the following formula $PV_k = \frac{s_y \sum_{j=0}^k \beta^j S_j}{g_y \sum_{j=0}^k \beta^j G_j}$, where $S = GDP, C$ and s_y is

the ratio to GDP (respectively 1 and $\frac{C}{GDP}$)

of several variables over the business cycle in the United States.⁹

Even with LBD, the model performs poorly. The volatility generated by the model, measured in term of standard deviation, is quite small respect to the corresponding moments observed in the data, whereas the auto-correlation is larger. Table 1.4 reports the standard deviations calculated for the data and for the models with and without LBD. In the data the GDP standard deviation is 1.5% over the period considered. The model without LBD can account for only one quarter of the volatility in the data. The model with LBD generate a higher volatility than the model without LBD, however its capability of accounting for the GDP fluctuation observed in the data is still limited. The statistics reported for the remaining variables are affected by the same problem. The standard deviation of each variable in terms of GDP standard deviation (the number reported in parenthesis) is also smaller than the corresponding value found in the data. Also in this case adding LBD improves in many cases the model's performance.¹⁰

Figure 1.10 shows the cross correlation functions of current GDP with lagged and leaded variables. The number of lags (leads) on the *x-axis* is measured in quarters. The model with LBD generates a cross correlation consistent with the data. However, there are two main exceptions. First, the contemporaneous correlation between GDP and inflation is positive in the data, whereas the model-based correlation is negative. Second, the correlation between the real wage and GDP is substantially larger than the corresponding value in the data.

Finally, figure 1.11 displays the auto correlation functions. Overall, the model based functions are larger than the corresponding data moments. Apart

⁹Moments for the data are calculated on logged variables, except for inflation and interest rate for which I consider the value in level. Variables are detrended by an Hodrick-Prescott (HP) filter with smoothing parameter 1,600. To calculate the moments for the models, each model is simulated over 264 periods. The first 100 observations are discarded so that the models and data have the same sample size. I generate 500 artificial samples. I report the average value over the drawn samples.

¹⁰Results from an additional analysis, not reported here, show that one of the main element that explains the low volatility in the models is the small value of the productivity shock auto-correlation process ρ_a . Using a larger value (around 0.90), while keeping all the other parameters at their baseline values, increases the volatility and make the model able to account for much of the fluctuation observed in the data.

for the behaviour of inflation, the model with and without LBD generate very similar values.

1.6 Conclusion

The first part of this chapter has presented an empirical and theoretical literature review on the effects of a government spending on several macroeconomic variables, in particular on private consumption and total factor productivity. Existing theoretical studies do not devote enough attention to the effects of government spending on productivity or require government spending to enter as an input into production function.

The main result of the chapter is to show that including a Learning-By-Doing mechanism in an otherwise standard new Keynesian DSGE model enables the model to replicate the increase in consumption observed in the data. I also show that with LBD even a completely wasteful government spending endogenously raises productivity.

In my model knowledge capital accumulation depends on the past level of hours worked. A positive government spending shock yields an increase in hours which in turn raises knowledge capital. The resulting increase in productivity increments the real wage and reduces marginal costs and hence the expected inflation path. The model generates a sufficient level of intra and inter-temporal effects that offset the negative wealth effect created by the expected increase in future taxes required for the government budget constraint to hold. This chapter also shows the effect of the increased productivity on the labour market and the role played by nominal frictions.

Table 1.1: Fixed parameters

Parameter		Value	Source/Target
φ	inverse of labour supply elasticity	3	standard value
β	households discount factor	0.995	capital-GDP ratio: 9.5
δ	capital depreciation rate	0.025	investment-GDP ratio: 24%
α	capital share	0.30	labour share: 2/3
λ_w	steady state wage mark-up	0.05	steady-state wage mark-up: 5%
λ_f	steady state price mark-up	0.05	steady-state price mark-up: 5%
$\frac{G}{GDP}$	government spending-GDP ratio	0.20	sample average
ι_p	price indexation to past inflation	0	Christiano et al. (2010)
u''	capital utilization cost	0.01	elasticity of capital utilization: 3.25%

Table 1.2: Estimated parameters and standard errors

Parameter		Model	
		Baseline	LBD off
<i>Shocks process</i>			
σ_r	monetary shock: standard deviation	0.21 (0.021)	0.20 (0.017)
σ_a	productivity shock: standard deviation	0.47 (0.030)	0.48 (0.029)
σ_g	government shock: standard deviation	0.84 (0.039)	0.87 (0.042)
ρ_g	government spending: autocorrelation	0.95 (0.008)	0.93 (0.010)
ρ_a	productivity shock: autocorrelation	0.77 (0.037)	0.66 (0.034)
<i>Structural parameters</i>			
ρ_r	monetary rule: interest smoothing	0.76 (0.025)	0.83 (0.026)
ϕ_π	monetary rule: inflation	1.84 (0.489)	1.37 (0.370)
ϕ_{gdp}	monetary rule: GDP growth	0.65 (0.254)	0.34 (0.152)
ζ_w	probability of wage fixed	0.60 (0.037)	0.63 (0.035)
ι_w	wage indexation to past inflation	0.05 (0.209)	0.66 (0.520)
ζ_p	probability of price fixed	0.66 (0.028)	0.91 (0.011)
h	consumption habit	0.64 (0.041)	0.77 (0.030)
S''	investment adjustment cost	6.27 (1.393)	4.17 (0.945)
μ_n	Learning-By-Doing (response to past hours)	0.54 (0.073)	-
ρ_x	Learning-By-Doing (autocorrelation)	0.60 (0.061)	-

Table 1.3: Present value government spending multipliers

	Data		Model: Baseline		Model: LBD off	
	<i>GDP</i>	<i>C</i>	<i>GDP</i>	<i>C</i>	<i>GDP</i>	<i>C</i>
impact	1.067	0.244	1.072	0.009	0.949	-0.034
after 4 quarters	0.728	0.264	1.230	0.059	0.888	-0.071
after 8 quarters	0.738	0.399	1.380	0.096	0.820	-0.106
after 20 quarters	0.742	0.553	1.387	0.056	0.644	-0.175

Table 1.4: Standard deviation (standard deviation relative to GDP)

	Data	Model with LBD	Model w/o LBD
GDP	1.50 (1.00)	0.60 (1.00)	0.40 (1.00)
Consumption	0.83 (0.56)	0.19 (0.32)	0.18 (0.44)
Inflation	0.28 (0.19)	0.06 (0.10)	0.02 (0.06)
Nominal interest rate	0.42 (0.28)	0.06 (0.10)	0.05 (0.14)
Wages	0.92 (0.62)	0.36 (0.60)	0.19 (0.47)

Notes: Quarterly percentage points

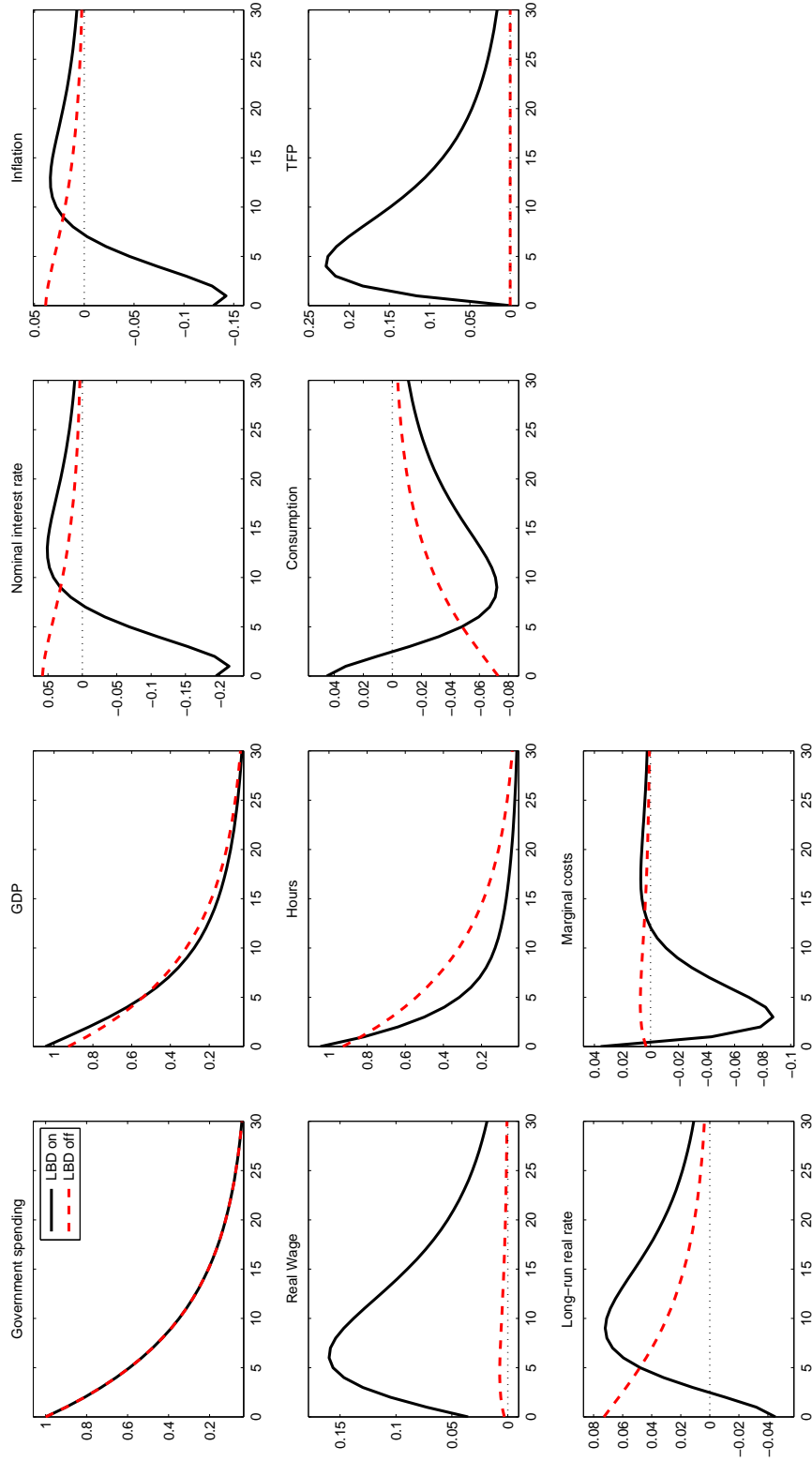


Figure 1.1: DSGE responses for the simplified economy with and without LBD. This figure shows impulse responses to a government spending shock equal to 1% of GDP for the simplified economy with LBD (black solid line) and without LBD (dashed red line). Notes: Responses are expressed in percentage deviation from steady state with the exception of nominal interest rate and inflation which are measured as annualized percentage points deviation from steady state.

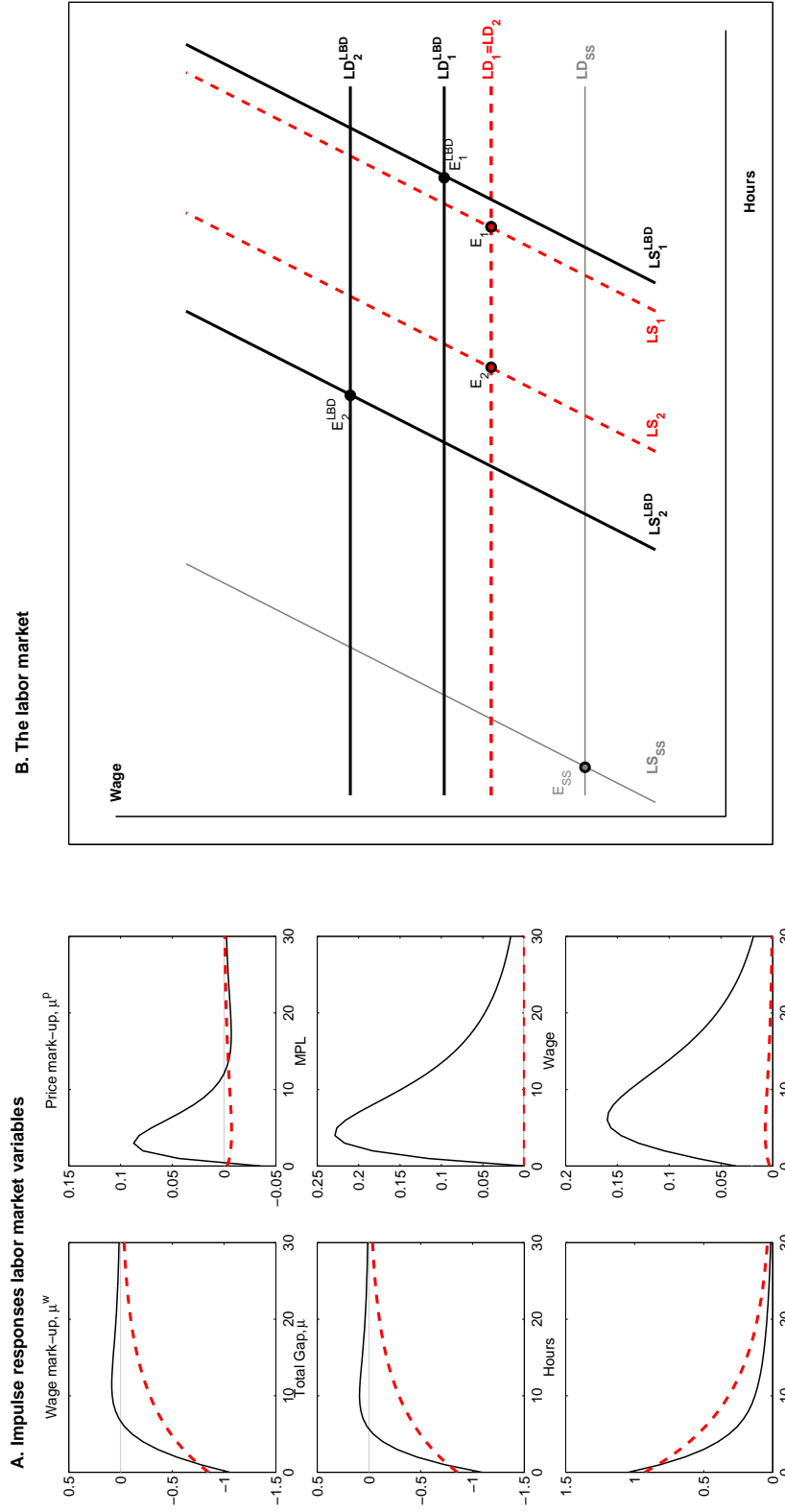


Figure 1.2: The labour market with and without LBD. This figure shows the labour market dynamics with LBD (black solid line) and without LBD (dashed red line). (A) shows the impulse responses to a government spending shock equal to 1% of GDP for the variables determining the labour market equilibrium. (B) illustrates the labour demand and the labour supply functions. Notes: see notes fig. 1.1.

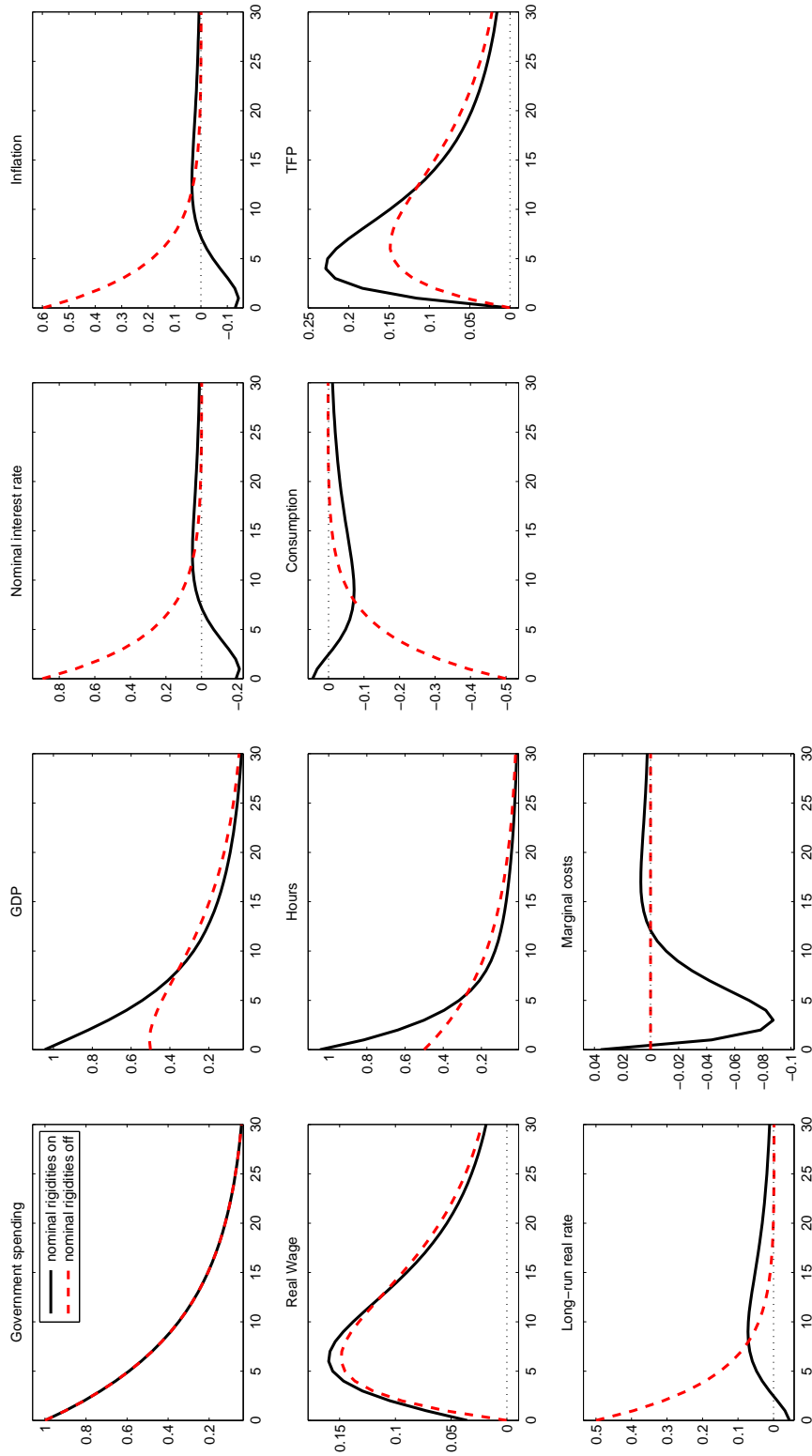


Figure 1.3: DSGE responses for the simplified economy with and without nominal rigidities. This figure shows impulse responses to a government spending shock equal to 1% of GDP for the simplified economy incorporating LBD, with nominal rigidities (black solid line) and without nominal rigidities (dashed red line). Notes: see notes fig. 1.1.

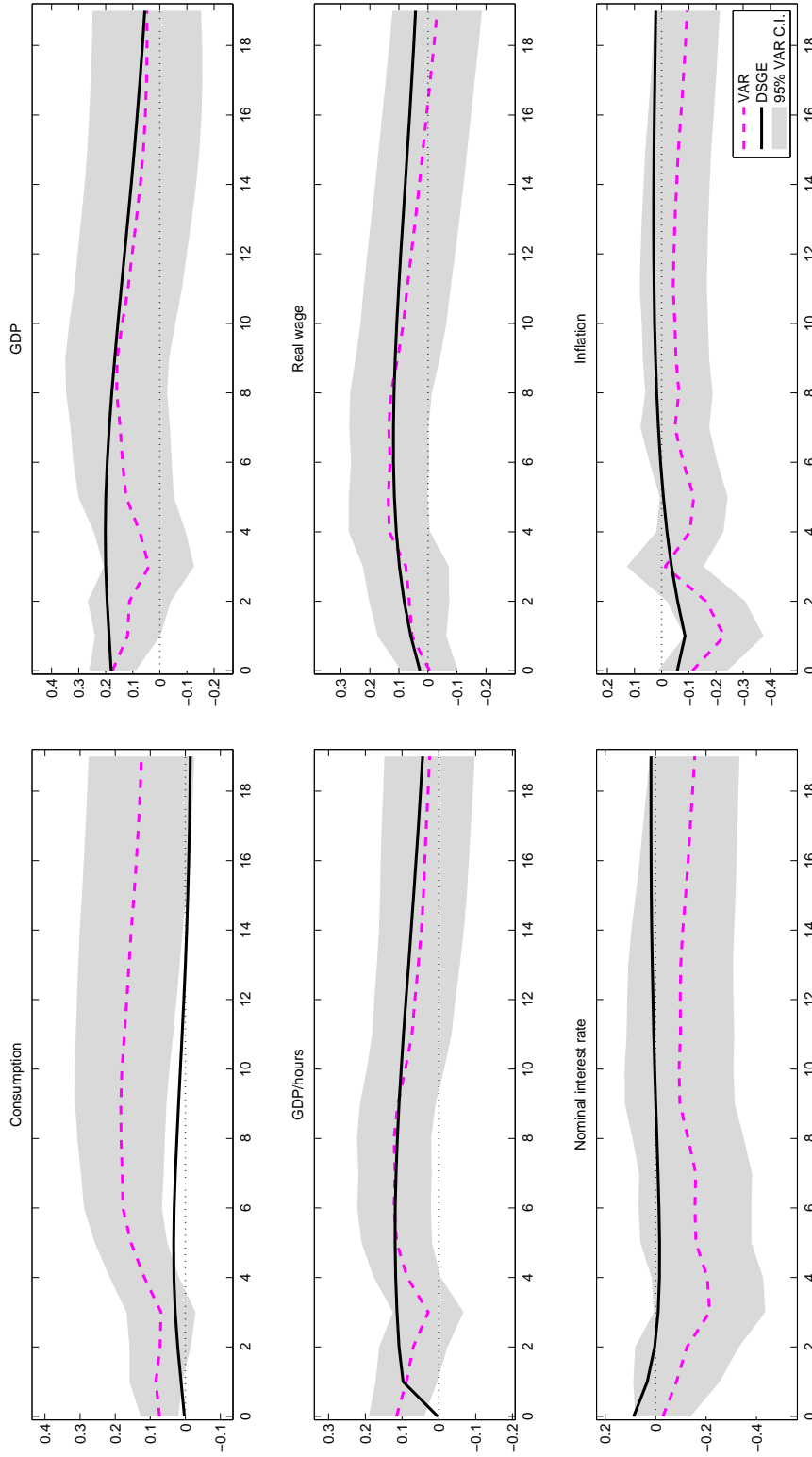


Figure 1.4: Responses to a government spending shock: VAR and baseline DSGE. This figure shows impulse responses to a positive government spending shock.

Notes: Responses are expressed in percentage deviation from steady state (or pre-shock period for the VAR) with the exception of the nominal interest rate and inflation which are measured as annualized percentage points deviation from steady state. Time on the x -axis is measured in quarters. The shock is equal to one standard deviation innovation.

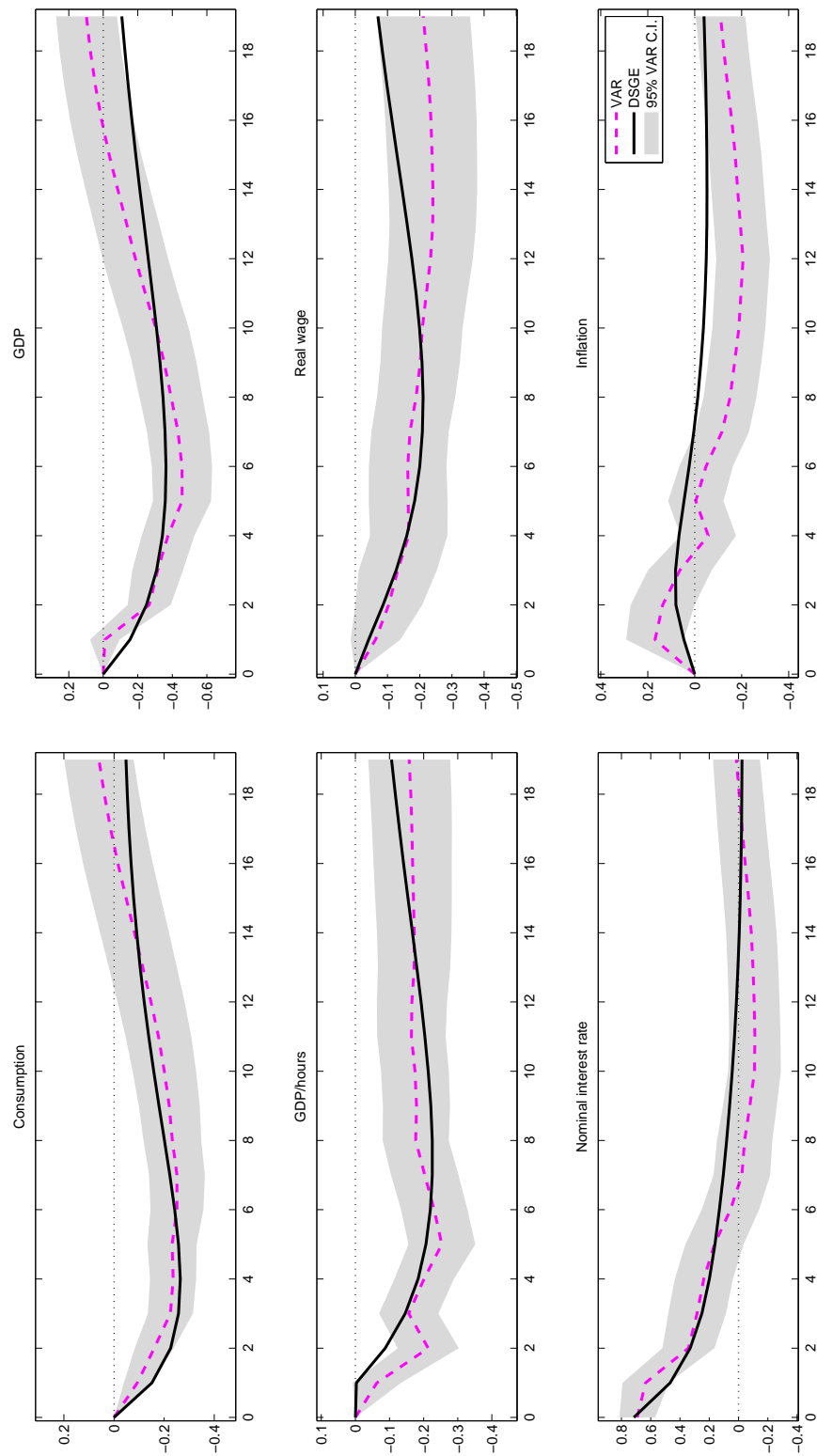


Figure 1.5: Responses to a monetary policy shock: VAR and baseline DSGE. This figure shows impulse responses to an increase in the nominal interest rate.
Notes: see fig. 1.4.

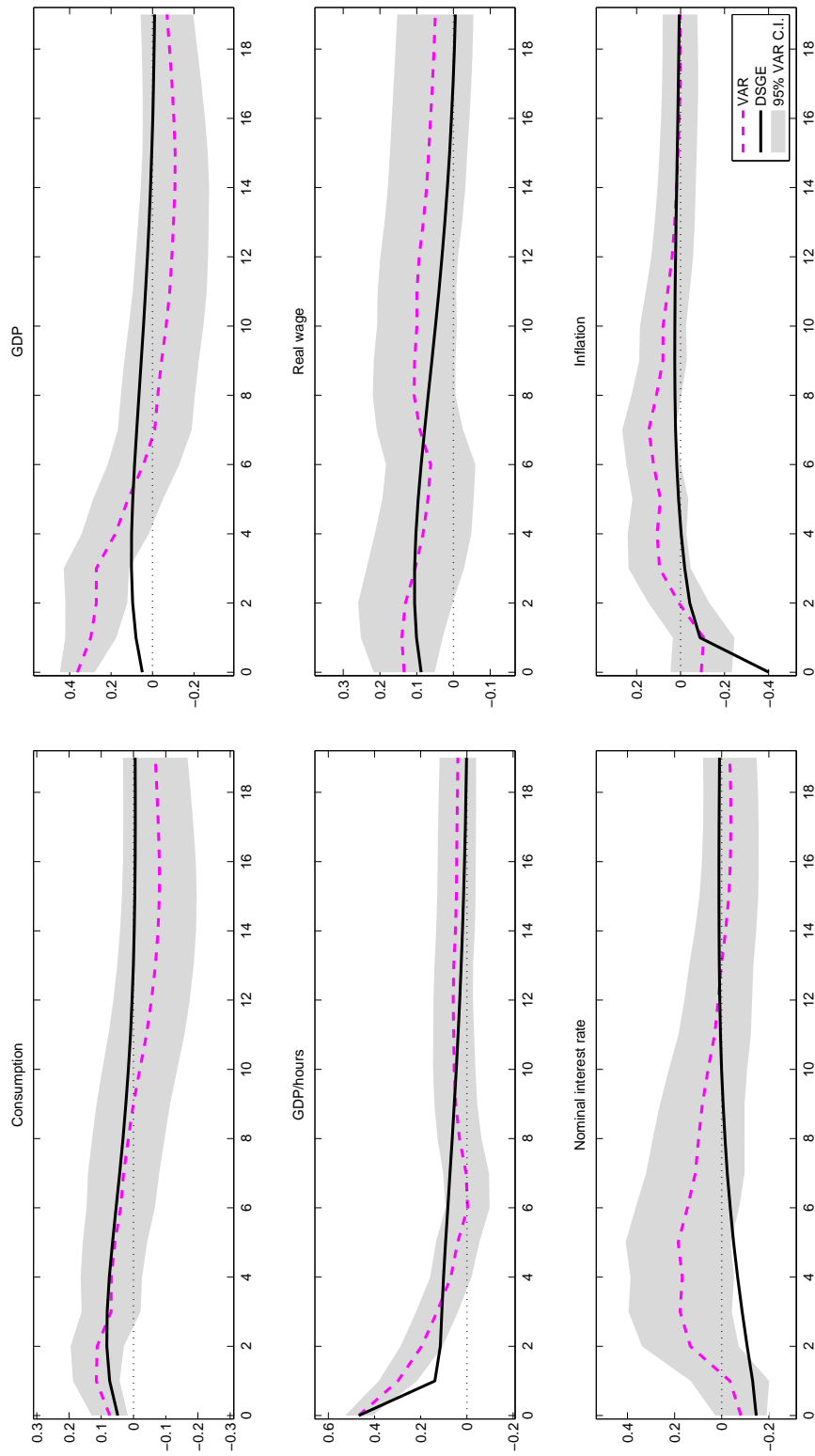


Figure 1.6: Responses to a productivity shock: VAR and baseline DSGE. This figure shows impulse responses to a positive productivity shock.
Notes: see fig. 1.4.

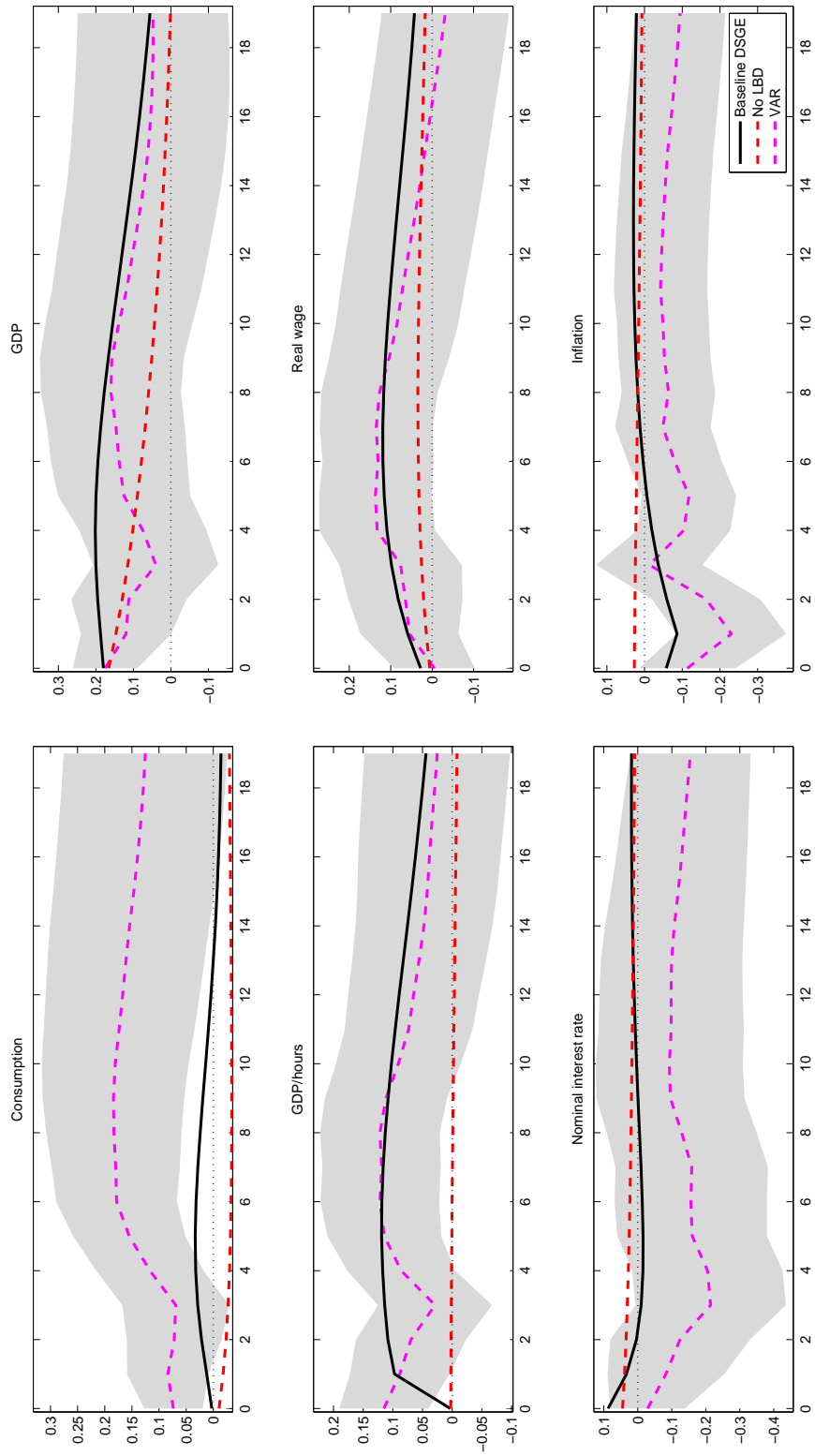


Figure 1.7: Responses to a government spending shock: baseline DSGE and alternative specifications. This figure shows impulse responses to a positive government spending shock for different DSGE specifications and for the VAR model.

Notes: see fig. 1.4.

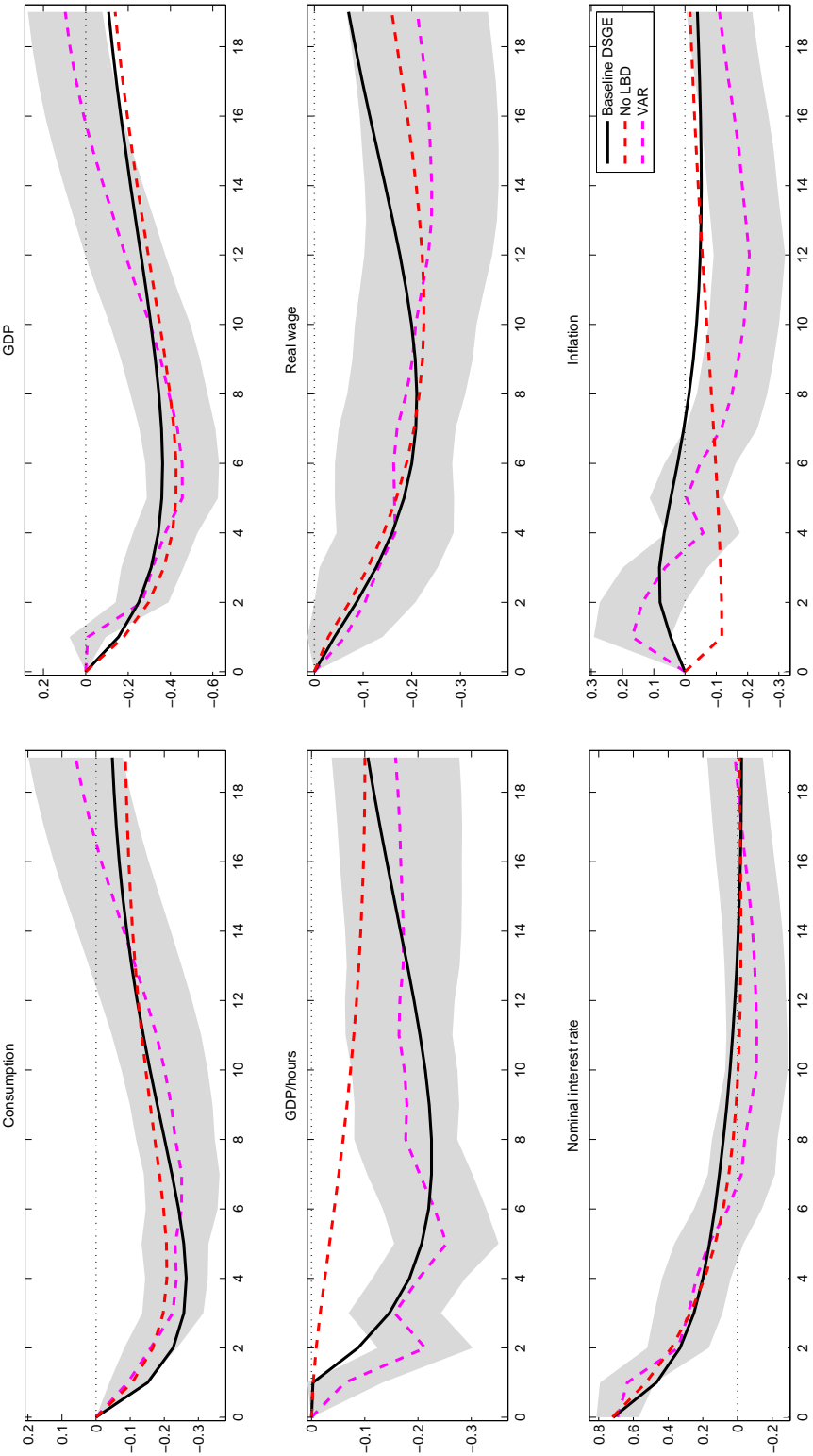


Figure 1.8: Responses to a monetary policy shock: baseline DSGE and alternative specifications. This figure shows impulse responses to an increase in the nominal interest rate for different DSGE specifications and for the VAR model.
Notes: see fig. 1.4

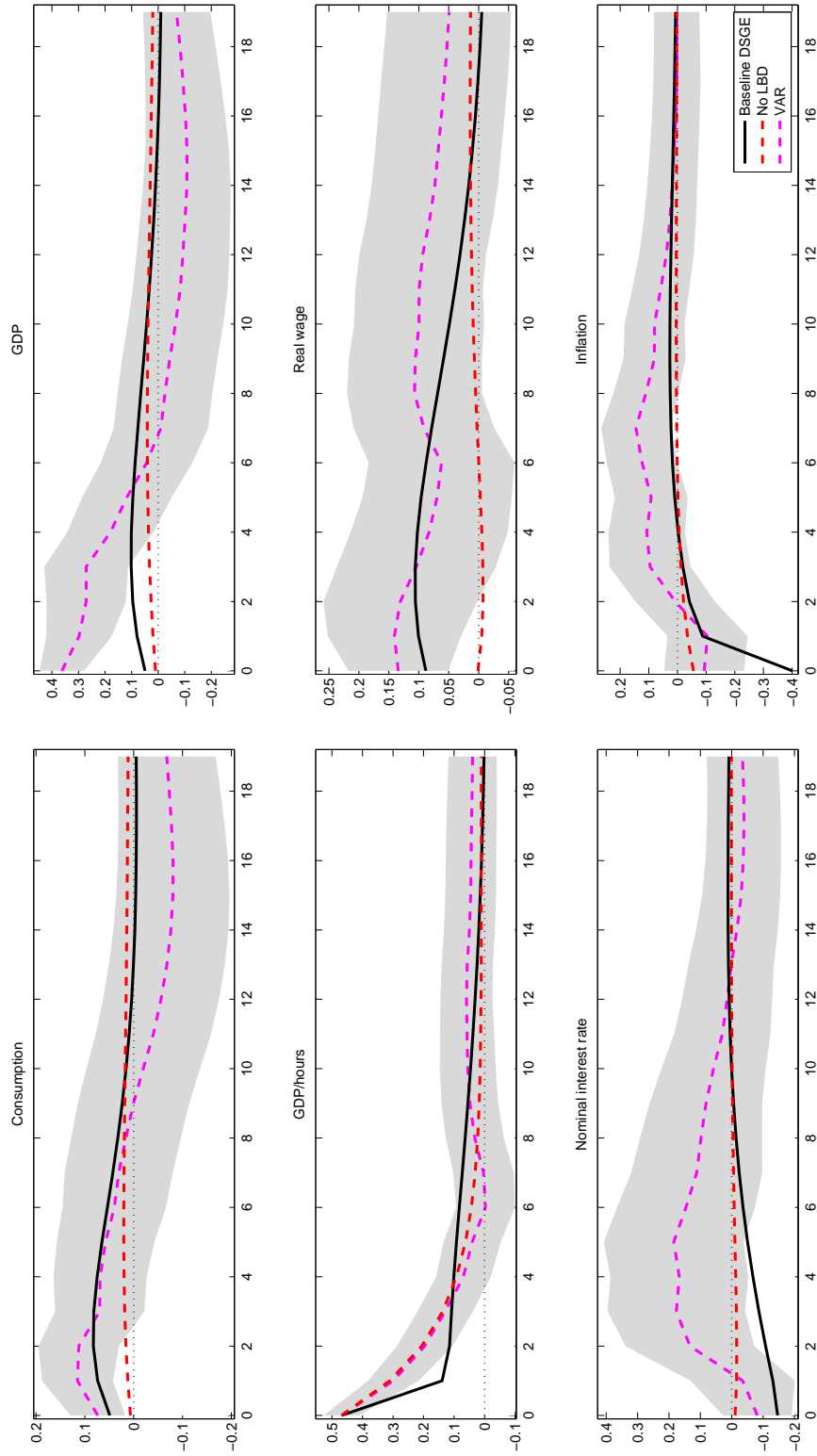


Figure 1.9: Responses to a productivity shock: baseline DSGE and alternative specifications. This figure shows impulse responses to a positive productivity shock for different DSGE specifications and for the VAR model. Notes: see fig. 1.4

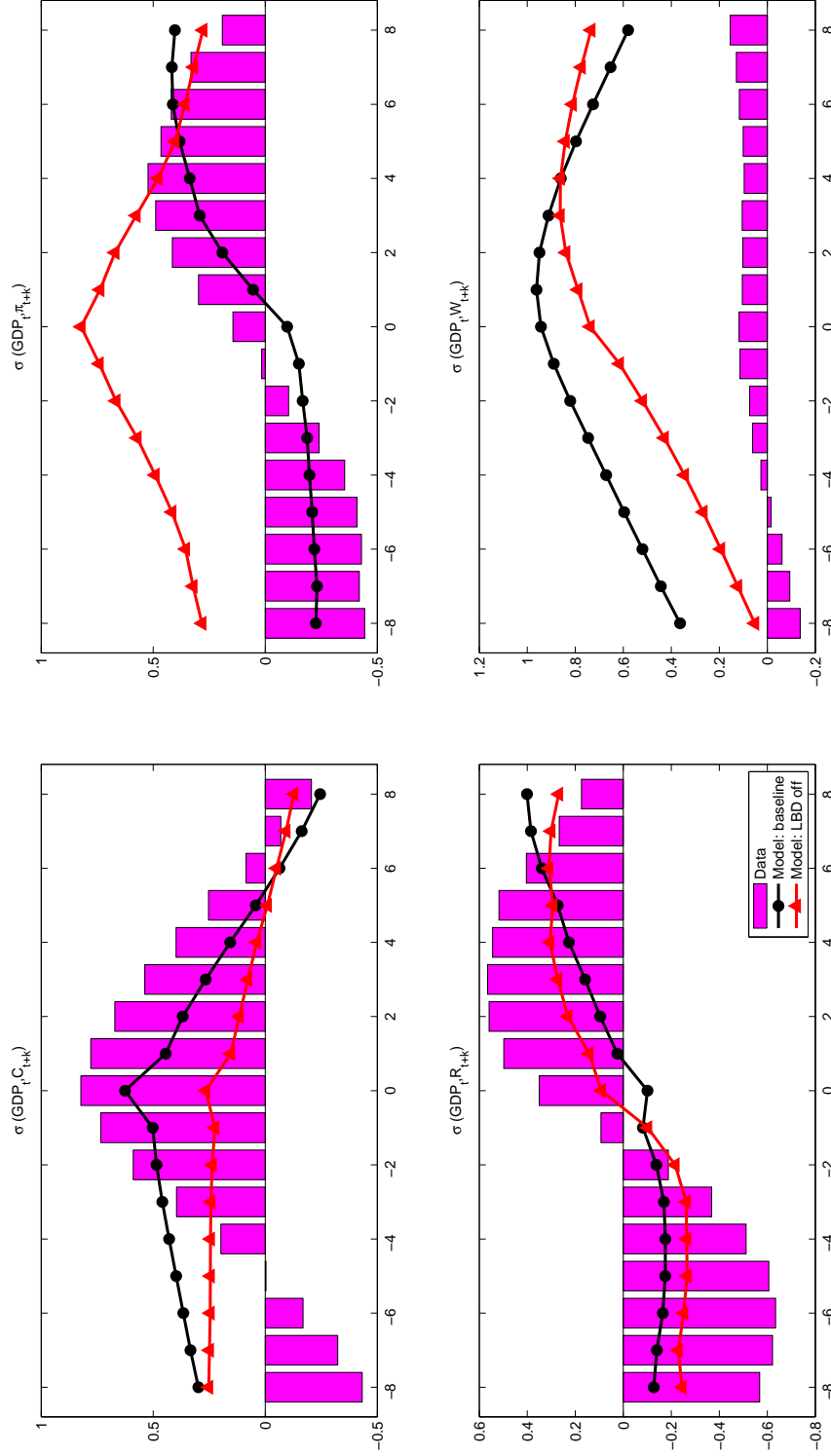


Figure 1.10: The actual and model-based cross-correlation functions with GDP.
Notes: The number of lags (leads) k on the x -axis is measured in quarters.

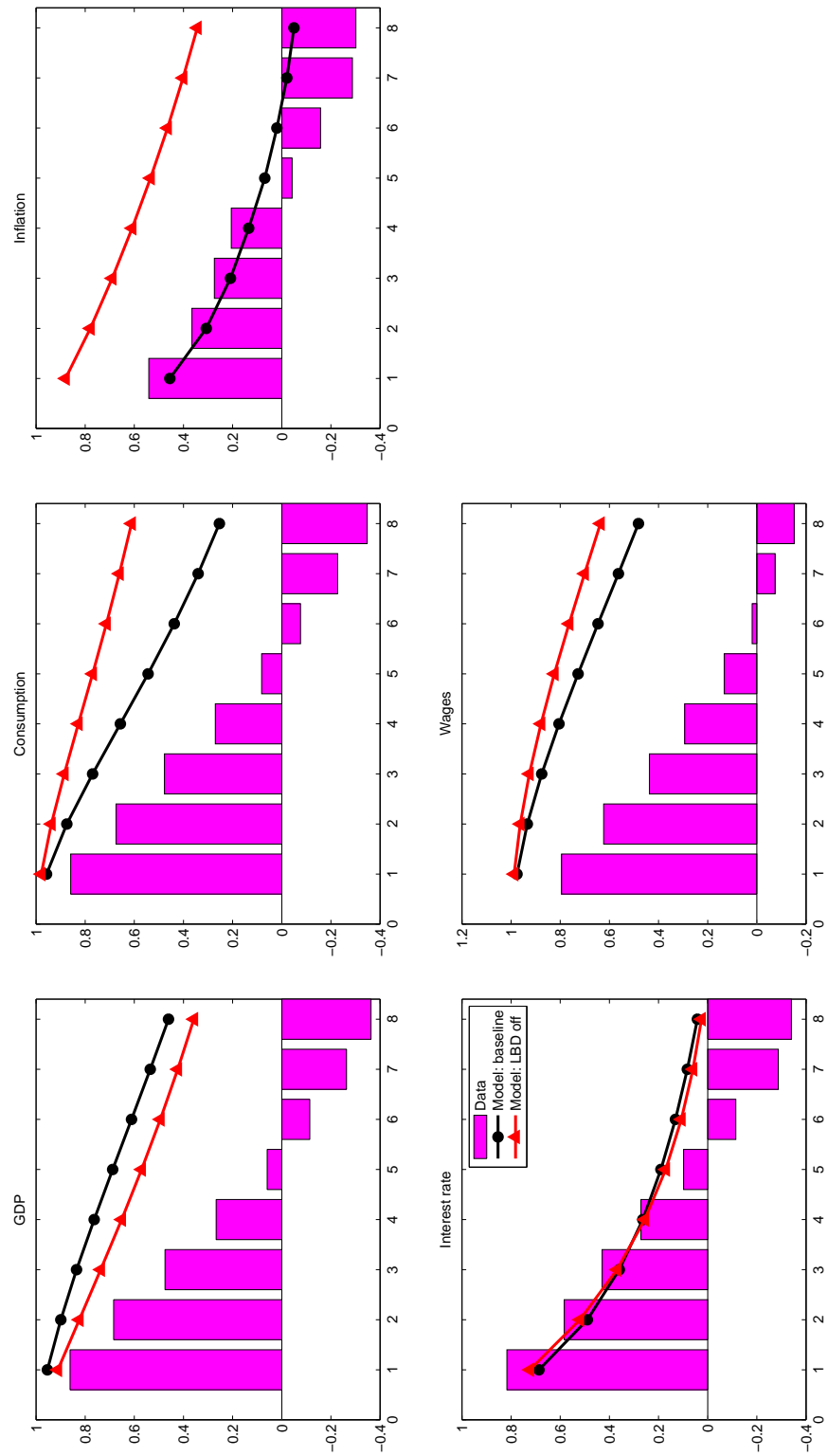


Figure 1.11: The actual and model-based auto-correlation functions.
Notes: The number of lags on the x -axis is measured in quarters.

APPENDIX A

Appendix to chapter 1

A.1 Data

This section describes more in details data employed in the estimation of the model presented in the main text.

Population: Civilian Noninstitutional Population (CNP16OV). Source: FRED, Federal Reserve Bank of ST. Louise. Note: average of monthly figures.

Gross domestic product deflator: Price Index for Gross Domestic Product, Table 1.1.4. line 1. Source: Bureau of Economic Analysis (BEA). Note: Index numbers, 2009=100. Seasonally adjusted.

GDP: Gross Domestic Product, Table 1.1.5 line 1. Source: Bureau of Economic Analysis (BEA). Note: Seasonally adjusted at annual rates.

Government spending: Government consumption expenditures and gross investment, Table 1.1.5 line 21. Source: Bureau of Economic Analysis (BEA). Note: Seasonally adjusted at annual rates.

Consumption: non-durable goods+services, Table 1.1.5 lines 5 and 6. Source: Bureau of Economic Analysis (BEA). Note: Seasonally adjusted at annual rates.

Interest rate: Effective Federal Funds Rate (FEDFUNDS). Source: FRED, Federal Reserve Bank of ST. Louise. Note: average of monthly figures. Not Seasonally Adjusted.

Debt: Federal Debt: Total Public Debt (GFDEBTN). Source: FRED, Federal Reserve Bank of ST. Louise. Note: not seasonally adjusted.

Wage: Nonfarm Business Sector: Compensation Per Hour (COMPNFB). Source: FRED, Federal Reserve Bank of ST. Louise. Note: Index numbers 2005=100. Seasonally Adjusted.

Employment: civilian employment (CE16OV), thousands, persons 16 years of age and older. Source: FRED, Federal Reserve Bank of ST. Louise. Note: seasonally adjusted.

Average Hours: Nonfarm Business Sector: Average Weekly Hours (PRS85006023). Source: FRED, Federal Reserve Bank of ST. Louise. Note: Index numbers 2005=100. Seasonally Adjusted.

All quantity variables are expressed in log of real per capita amounts using the GDP price index and the population measure described above. Per capita total hours is obtained multiplying average hours by employment and dividing by population. Inflation is the log differences in the GDP price index.

A.2 Model derivation

Apart from the inclusion of LBD, the model presented is a standard New Keynesian DSGE model as employed in Smets and Wouters (2007). In this part I list the first order conditions, the steady state values and the set of log-linearized equations. In what follow the symbol “ \sim ” denotes variables expressed in real term.

A.2.1 First order conditions

Households.

Since in equilibrium all households make the same decision, the i index can be dropped. Households first order conditions respect to bond holding B_t , consumption C_t , investment I_t , capital \bar{K}_t and capital utilization u_t are:

$$\lambda_t^I \mathbb{E}_t [\pi_{t+1}] = \beta \mathbb{E}_t [\lambda_{t+1}^I] R_t \quad (\text{A.1})$$

$$\lambda_t^I = \frac{1}{(C_t - hC_{t-1})} - \frac{h\beta}{(\mathbb{E}_t [C_{t+1}] - hC_t)} \quad (\text{A.2})$$

$$\lambda_t^I = \lambda_t^K \left[1 - S \left(\frac{I_t}{I_{t-1}} \right) - S' \left(\frac{I_t}{I_{t-1}} \right) \frac{I_t}{I_{t-1}} \right] + \beta \mathbb{E}_t [\lambda_{t+1}^K] \left[S' \left(\frac{\mathbb{E}_t [I_{t+1}]}{I_t} \right) \left(\frac{\mathbb{E}_t [I_{t+1}]}{I_t} \right)^2 \right] \quad (\text{A.3})$$

$$\lambda_t^K = \beta \mathbb{E}_t [\lambda_{t+1}^I] \left(\mathbb{E}_t [\tilde{R}_{t+1}^k u_{t+1}] - a(\mathbb{E}_t [u_{t+1}]) \right) + \beta (1 - \delta) \mathbb{E}_t [\lambda_{t+1}^K] \quad (\text{A.4})$$

$$\tilde{R}_t^k = a'(u_t) \quad (\text{A.5})$$

where $\lambda_t^I \equiv P_t \bar{\lambda}_t^I$ and $\bar{\lambda}_t^I$ and λ_t^K are the multipliers associated respectively to the budget constraint (1.13) and the capital evolution constraint (1.14).

Wage setting

The first order condition for the wage setting problem described in (1.18) can be rearranged as:

$$\mathbb{E}_t \sum_{s=0}^{\infty} \zeta_w^s \beta^s \left[\left(X_{t,s}^W W_t^{rel} \frac{\tilde{W}_t}{\tilde{W}_{t+s}} \right)^{-\frac{1+\lambda_w}{\lambda_w}} N_{t+s} \right] \lambda_{t+s}^I \times \left\{ (1 + \lambda_w) \left(X_{t,s}^W W_t^{rel} \frac{\tilde{W}_t}{\tilde{W}_{t+s}} \right)^{-\frac{(1+\lambda_w)\varphi}{\lambda_w}} \frac{N_{t+s}^\varphi}{\lambda_{t+s}^I} - X_{t,s}^W W_t^{rel} \tilde{W}_t \right\} = 0 \quad (\text{A.6})$$

where $X_{t,s}^W \equiv \frac{\prod_{l=1}^s (\pi)^{(1-i_w)(\pi_{t+l-1})^{i_w}}}{\prod_{l=1}^s \pi_{t+l}}$ and $W_t^{rel} \equiv \frac{\tilde{W}_t^{new}}{\tilde{W}_t}$ is the relative wage chosen

by those households that are allowed to re-optimize their wage respect to the level of wages at time t . Wage evolution (1.20) expressed in term of relative wage became:

$$\left(\tilde{W}_t\right)^{-\frac{1}{\lambda_w}} = (1 - \zeta_w) \left(W_t^{rel} \tilde{W}_t\right)^{-\frac{1}{\lambda_w}} + \zeta_w \left[\frac{(\pi)^{(1-i_w)(\pi_{t-1})^{i_w}}}{\pi_t} \tilde{W}_{t-1} \right]^{-\frac{1}{\lambda_w}} \quad (\text{A.7})$$

Firms.

Firms cost minimization problem yields the following demand for capital and labour inputs:

$$R_t^k = \alpha MC_t \frac{Y_t}{K_t} \quad (\text{A.8})$$

$$W_t = MC_t (1 - \alpha) \frac{Y_t}{N_t} \quad (\text{A.9})$$

where the j index has been dropped because input prices are given for firms and hence inputs demand is the same across all firms. Combining the two equations above yields the input ratio (1.7). The ratio can also be expressed in real term:

$$\frac{K_t}{N_t} = \frac{\alpha}{1 - \alpha} \frac{\tilde{W}_t}{\tilde{R}_t^k} \quad (\text{A.10})$$

Combining (A.8) and (A.9) together with the production function (1.4) yields the expression for nominal marginal costs in (1.8). In real terms marginal costs are:

$$\tilde{M}C_t = \frac{1}{\alpha^\alpha (1 - \alpha)^{(1-\alpha)}} \frac{\tilde{W}_t^{(1-\alpha)} \tilde{R}_t^{K \alpha}}{A_t X_t^{(1-\alpha)}} \quad (\text{A.11})$$

Price setting.

Firms first order condition for the optimal price setting problem in (1.10) is:

$$\mathbb{E}_t \sum_{s=0}^{\infty} (\zeta_p \beta)^s \left(\frac{\lambda_{t+s}}{\lambda_t} \right) (X_{t,s})^{-\frac{1+\lambda_f}{\lambda_f}} \left\{ \left[(1 + \lambda_f) \tilde{M} C_{t+s} - P_t^{rel} (X_{t,s}) \right] \right\} = 0 \quad (\text{A.12})$$

where $X_{t,s} = \frac{\prod_{l=1}^s (\pi)^{(1-i_p)(\pi_{t+l-1})^{i_p}}}{\prod_{l=1}^s \pi_{t+l}}$ and the relative price P_t^{rel} is defined as $P_t^{rel} \equiv \frac{P_t^{new}}{P_t}$, where P_t^{new} is the new price chosen by those firms able to re-optimize their price.

Price evolution (1.11) can be rewritten in terms of relative price as:

$$(1 - \zeta_p) (P_t^{rel})^{-\frac{1}{\lambda_f}} + \zeta_p \left(\frac{\pi_{t-1}^{\iota_p} \pi^{(1-\iota_p)}}{\pi_t} \right)^{-\frac{1}{\lambda_f}} = 1 \quad (\text{A.13})$$

Equation (A.12) and (A.13) can be combined to obtain the new-Keynesian Phillips curve.

A.2.2 Equilibrium equations

The model equilibrium is defined by equations (A.1), (A.2), (A.3), (A.4), (A.5), (A.6), (A.7), (A.10), (A.11), (A.12), (A.13), plus the production function (1.4), the productivity shock (1.5), the LBD accumulation process (1.6), the capital accumulation process (1.14), the monetary policy rule (1.21), the definition of GDP (1.22), the government spending process evolution (1.24), the goods market clearing condition (1.25) and the definition of effective capital discussed in the main text.

A.2.3 Steady states

Assuming inflation is zero at steady state equilibrium, steady states values in term of fixed parameters are:

$$MC = \frac{1}{1 + \lambda_f} \quad (\text{A.14})$$

$$R^k = \frac{1}{\beta} - (1 - \delta) \quad (\text{A.15})$$

$$\frac{K}{Y} = \alpha \frac{MC}{R^k} \quad (\text{A.16})$$

$$\frac{I}{Y} = \delta \frac{K}{Y} \quad (\text{A.17})$$

$$\frac{C}{Y} = 1 - \frac{I}{Y} - \frac{G}{Y} \quad (\text{A.18})$$

A.2.4 Log-linearized model

Let lower-case variables with “ $\hat{}$ ” denoting variables in log-deviation from steady states and where appropriate expressed in real term, the log-linearized equilibrium conditions around steady-states levels are given by:

$$\hat{\lambda}_t^I = \mathbb{E}_t [\hat{\lambda}_{t+1}^I] + \hat{r}_t - \mathbb{E}_t [\hat{\pi}_{t+1}] \quad (\text{A.19})$$

$$(1 - h\beta)(1 - h)\hat{\lambda}_t^I = -(1 + h^2\beta)\hat{c}_t + h\hat{c}_{t-1} + h\beta\mathbb{E}_t [\hat{c}_{t+1}] \quad (\text{A.20})$$

$$(1 + \beta)\hat{i}_t = \hat{i}_{t-1} + \beta\mathbb{E}_t [\hat{i}_{t+1}] + \frac{(\hat{\lambda}_t^K - \lambda_t^I)}{S''(1)} \quad (\text{A.21})$$

$$\begin{aligned} \hat{\lambda}_t^K - \hat{\lambda}_t^I &= [1 - \beta(1 - \delta)]\mathbb{E}_t [\hat{r}_{t+1}^k] + \beta(1 - \delta)\mathbb{E}_t [\hat{\lambda}_{t+1}^K - \hat{\lambda}_{t+1}^I] \\ &\quad - (\hat{r}_t - \mathbb{E}_t [\hat{\pi}_{t+1}]) \end{aligned} \quad (\text{A.22})$$

$$R^k \hat{r}_t^k = a''(u) \hat{u}_t \quad (\text{A.23})$$

$$\begin{aligned}\widehat{w}_t^{rel} &= \zeta_w \beta \left\{ \mathbb{E}_t [\widehat{w}_{t+1}^{rel}] + \mathbb{E}_t [\widehat{w}_{t+1}] - \widehat{w}_t - i_w \widehat{\pi}_t + \mathbb{E}_t [\widehat{\pi}_{t+1}] \right\} \\ &+ \frac{\lambda_w (1 - \zeta_w \beta)}{\lambda_w + (1 + \lambda_w) \varphi} \left\{ \varphi \widehat{n}_t - \widehat{\lambda}_t^I - \widehat{w}_t \right\}\end{aligned}\quad (\text{A.24})$$

$$\widehat{w}_t = i_w \widehat{\pi}_{t-1} - \widehat{\pi}_t + \widehat{w}_{t-1} + \frac{(1 - \zeta_w)}{\zeta_w} \widehat{w}_t^{rel} \quad (\text{A.25})$$

$$\widehat{r}_t^k + \widehat{k}_t = \widehat{n}_t + \widehat{w}_t \quad (\text{A.26})$$

$$\widehat{m}c_t = (1 - \alpha) (\widehat{w}_t - \widehat{x}_t) + \alpha \widehat{r}_t^k - a_t \quad (\text{A.27})$$

$$\widehat{\pi}_t = \frac{\iota_p}{(1 + \iota_p \beta)} \widehat{\pi}_{t-1} + \frac{\beta}{(1 + \iota_p \beta)} \mathbb{E}_t [\widehat{\pi}_{t+1}] + \frac{(1 - \zeta_p \beta) (1 - \zeta_p)}{\zeta_p (1 + \iota_p \beta)} \widehat{m}c_t \quad (\text{A.28})$$

$$\widehat{y}_t = (1 - \alpha) (\widehat{x}_t + \widehat{n}_t) + \alpha \widehat{k}_t + \widehat{a}_t \quad (\text{A.29})$$

$$\widehat{a}_t = \rho_a \widehat{a}_{t-1} + \varepsilon_t^a \quad (\text{A.30})$$

$$\widehat{x}_t = \rho_x \widehat{x}_{t-1} + \mu_n \widehat{n}_{t-1} \quad (\text{A.31})$$

$$\widehat{k}_t = (1 - \delta) \widehat{k}_{t-1} + \delta \widehat{i}_t \quad (\text{A.32})$$

$$\widehat{r}_t = \rho_r \widehat{r}_{t-1} + (1 - \rho_r) \left[\phi_\pi \widehat{\pi}_t + \phi_{gdp} \left(\widehat{gdp}_t - \widehat{gdp}_{t-1} \right) \right] + \varepsilon_t^r \quad (\text{A.33})$$

$$\widehat{gdp}_t = \frac{C}{Y} \widehat{c}_t + \frac{I}{Y} \widehat{i}_t + \frac{G}{Y} \widehat{g}_t \quad (\text{A.34})$$

$$\widehat{g}_t = \rho_g \widehat{g}_{t-1} + \varepsilon_t^g \quad (\text{A.35})$$

$$\widehat{y}_t = \frac{C}{Y} \widehat{c}_t + \frac{I}{Y} \widehat{i}_t + R^k \frac{K}{Y} \widehat{u}_t + \frac{G}{Y} \widehat{g}_t \quad (\text{A.36})$$

$$\widehat{k}_t = \widehat{u}_t + \widehat{k}_{t-1} \quad (\text{A.37})$$

A.3 Learning-By-Doing and the Taylor rule

The introduction of LBD also impacts on the ability of the monetary authority to control inflation expectations and, by implementing a Taylor rule, to bring about an unique and stable equilibrium. In fact, the traditional wisdom, summarized by the Taylor rule, requires that for any 1% variation in inflation, central bankers should change nominal interest rate by more than 1%. However, in a model with LBD the Taylor rule no longer assures the model

stability and, on the contrary, can lead to unstable solutions. To see this point I consider the simplified model presented in section 1.4.2 of the main text. Without loss of generality I also assume that government is absent and there are no wage frictions. I also assume that monetary authority targets expected inflation. This kind of model can be summarized by the following system of equations:

$$\hat{y}_t = \hat{n}_t + \hat{x}_t \quad (\text{A.38})$$

$$\hat{y}_t = \hat{c}_t \quad (\text{A.39})$$

$$\hat{n}_t + \hat{c}_t = \hat{w}_t \quad (\text{A.40})$$

$$\hat{r}_t = \phi_\pi \mathbb{E}_t [\hat{\pi}_{t+1}] \quad (\text{A.41})$$

where equation (A.38) is the production function, equation (A.39) is the market clearing condition, (A.40) states that the marginal rate of substitution between consumption and leisure must be equal to real wage and (A.41) is a Taylor rule targeting expected inflation. Equations (1.26)-(1.28) complete the model description. From (1.30) inflation can be stabilized controlling for the level of marginal costs. Plugging (A.40) into (1.28) and combining (A.38) and (A.39) marginal costs can be rewritten as:

$$\widehat{mc}_t = 2(\hat{c}_t - \hat{x}_t) \quad (\text{A.42})$$

Using the result showed in (1.29) equation above becomes:

$$\widehat{mc}_t = -2\mathbb{E}_t \sum_{s=0}^{\infty} (\hat{r}_{t+s} - \hat{\pi}_{t+1+s}) - 2\hat{x}_t \quad (\text{A.43})$$

Finally, plugging the monetary rule A.41 into the equation above yields:

$$\widehat{mc}_t = -2\mathbb{E}_t \sum_{s=0}^{\infty} (\phi_\pi - 1) \hat{\pi}_{t+1+s} - 2\hat{x}_t \quad (\text{A.44})$$

To see how the Taylor principle works, first consider a model without LBD, so that the last term in the equation (A.44) disappears. Suppose the economy is hit by a shock that increases marginal costs and inflation. In the attempt to stabilize inflation, the central bank raises the nominal interest rate. If $\phi_\pi > 1$ it means that nominal interest rate increase more than inflation. Hence, as far as inflation is above steady state, marginal costs decline (see (A.44)). In fact an increase in the real interest rate, by the Euler equation described in (1.29), and considering the market clearing condition described in the equation (A.39) leads to a reduction in the output, which in turn brings a reduction in the marginal costs and hence, by equation (1.30), in the level of inflation. Thus, the economy reverts to the steady state level. Now consider the case with LBD. As in the previous example the economy is hit by a shock that increase inflation and the monetary authority reacts by increasing the interest rate. However, the LBD mechanism adds a new element to the story described above. A reduction in the output, leads to fall in the hours worked and, by the LBD process, to a decrease in the level of stock of knowledge and hence, as described in equation (A.44) to a pressure on the level of marginal costs. If the LBD mechanism is strong enough, the increase in the nominal interest rate leads to an increase in the level of inflation. In this case, inflation expectation become self-fulfilling. Central banker is no longer able to control inflation expectation and hence the economy fluctuates between booms and recessions.

A.4 Initial guess and estimated values

Since the optimization routine employed is able to find only a local minimum, I performed several draws to verify that my estimates are actually a global minimum. In my exercise I randomly selected the initial guess within a range of plausible values. I have considered 300 draws. The initial guess and the corresponding final estimates are reported in figures A.1-A.2. The draws are sorted in ascending order by the value of the loss function defined in equation (1.38). As figures show, my optimization routine converges to the same values in most cases.

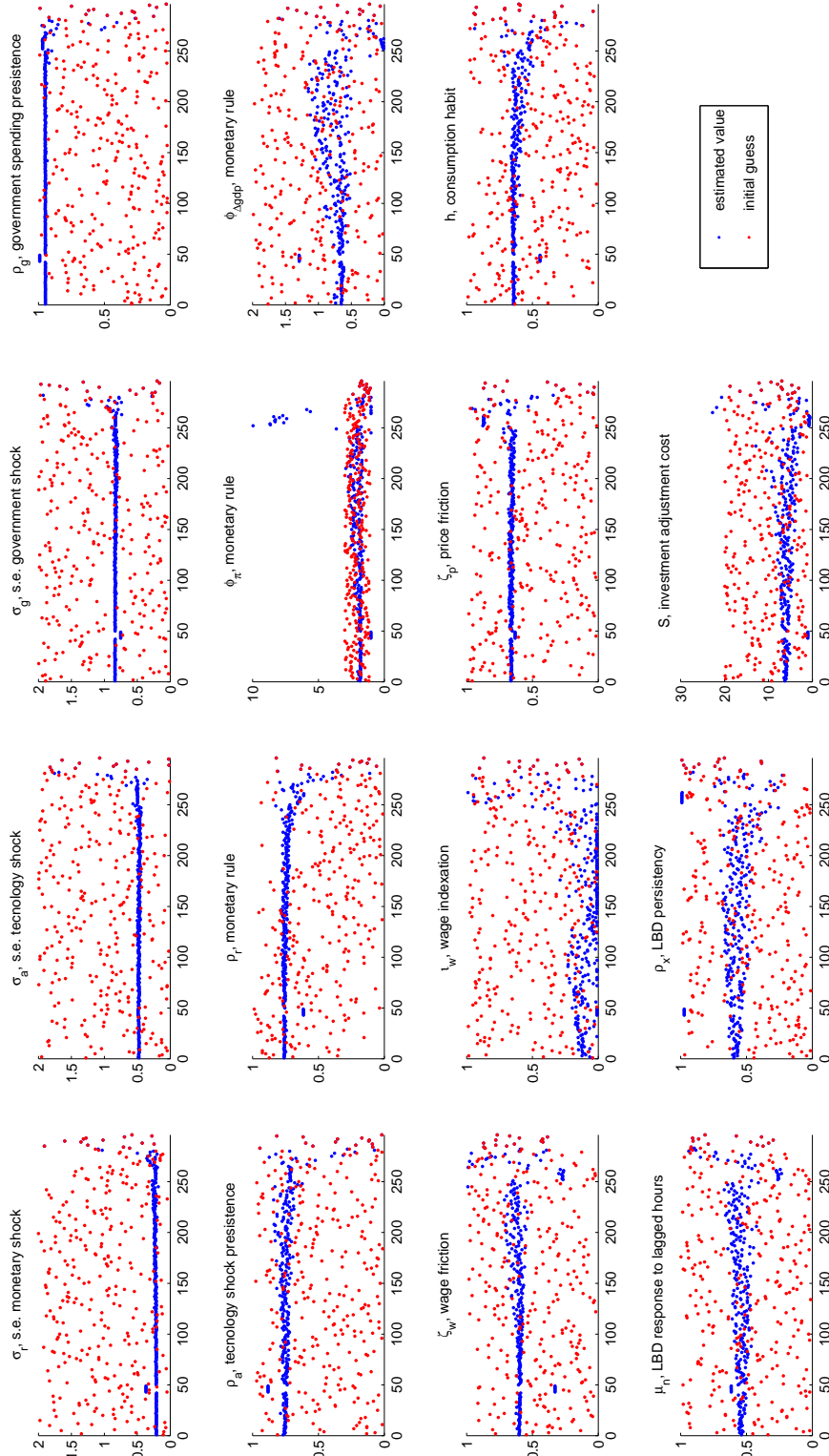


Figure A.1: Estimation sensitivity analysis: initial guess and obtained estimates. Baseline model.

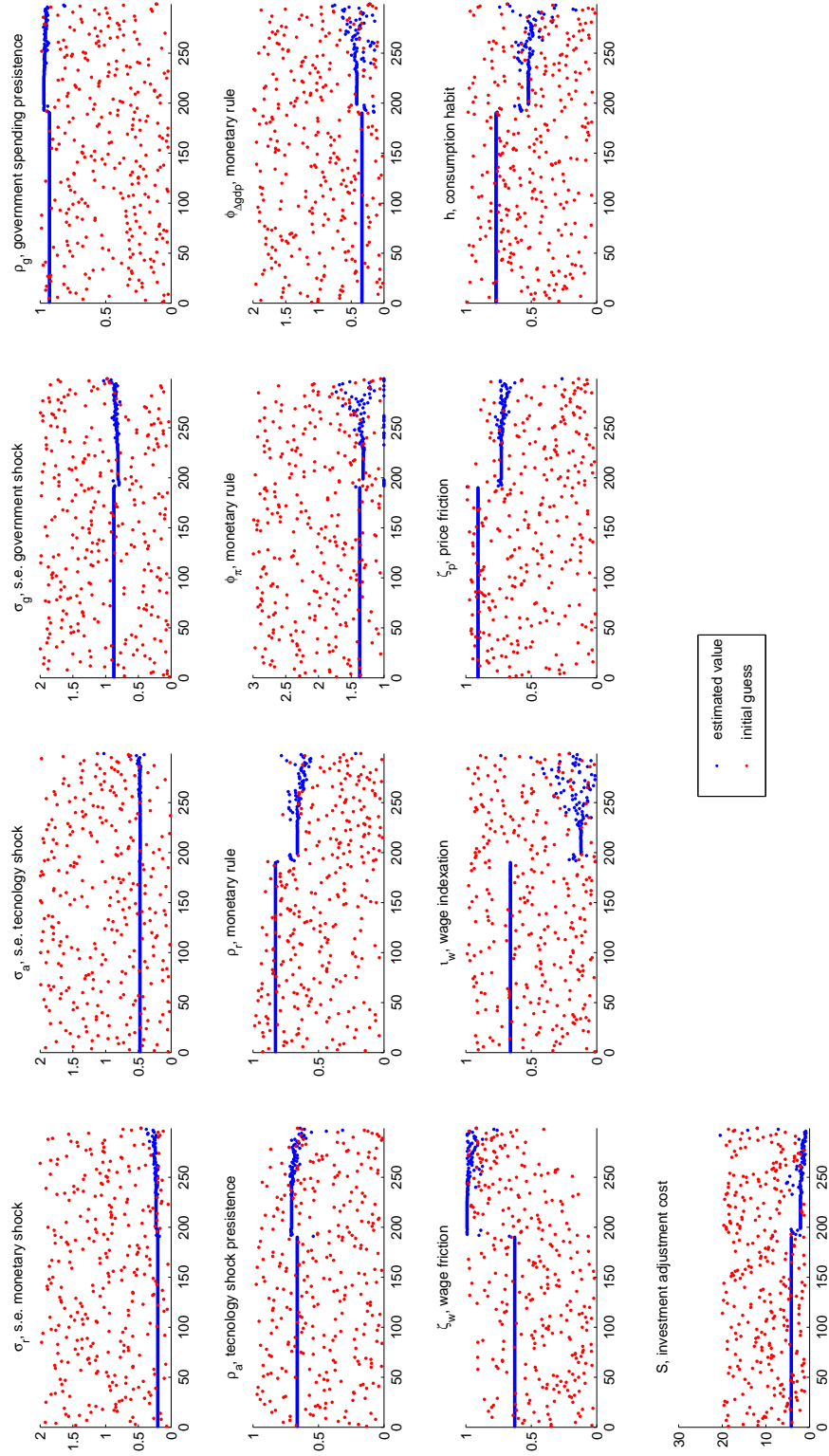


Figure A.2: Estimation sensitivity analysis: initial guess and obtained estimates. Model without LBD.

CHAPTER 2

The consumption real exchange rate puzzle: can Learning-by-Doing be the solution?

2.1 Introduction

In the first chapter I have discussed empirical and theoretical evidences of the effects of a government spending shock on domestic economic activity. More recently attention has been directed to the external sector of the economy and in particular to the consequences on the real exchange rate. The empirical evidence of a depreciation of the real exchange rate following a positive government expenditure shock is hard to reconcile with standard inter-temporal optimizing models. In these models the expected increase in taxes, needed for the inter-temporal government budget constraint to hold, generates a strong negative wealth effect which induces households to reduce consumption and increase labour supply. Under the assumption of international risk sharing, these models predict a co-movement between consumption and the real exchange rate, measured as the price of the foreign consumption basket in units of the home one. Thus, by predicting a decrease in private consumption they also fail to account for the real exchange rate depreciation.

This chapter shows how introducing the Learning-by-Doing (LBD) mechanism à la Chang et al. (2002) presented in the first chapter in an otherwise standard open economy DSGE model, generates a response of the real exchange rate to changes in government expenditure that is consistent with empirical

evidences.

The first part of the present chapter provides new evidences on the government spending effects. I use quarterly data for the U.S. for the period 1964 to 2006 to estimate a VAR model. Following Blanchard and Perotti (2002) I identify the government spending structural shock by assuming that government spending is predetermined within the quarter. I find that an exogenous increase in government spending produces several effects. First output, consumption and the real wage rise. Second, the real exchange rate depreciates and the trade balance deteriorates. Third, I find that inflation and the nominal interest rate decrease. Finally, and most important since it is the central motivation for considering the LBD mechanism, I find a large and persistent increase in total factory productivity.

The second part of the chapter introduces a LBD mechanism in a two-country version of an otherwise standard new Keynesian DSGE model. As in Chang et al. (2002) the level of output produced depends on the workers' skills with the latter evolving according to a LBD mechanism, so that past work experience affects the current level of skills. In contrast with the standard model, a positive government spending shock produces an increase in consumption and total factor productivity, as already discussed in the previous chapter, and a depreciation of the real exchange rate.

As discussed in chapter 1, these results are derived from the fact that in the model with LBD the increase in government spending leads to an endogenous increase in total factor productivity through the LBD mechanism. The resulting decline in the long term real interest rate increases consumption and, under the assumption of complete market, causes a depreciation of the real exchange rate.

The theoretical literature has proposed different explanations to solve the consumption-real exchange rate puzzle generated by a government spending shock.

Basu and Kollmann (2013) analyse the effect of a change in productive government spending on the real exchange rate. However, their model requires government spending to enter in the production function directly and fail to explain the observed increase in TFP when government spending is entirely

wasteful.

Erceg et al. (2005) examine an open economy with Rule-of-Thumb consumers proposed in Galí et al. (2007). The model generates an increase in consumption but cannot replicate the real exchange rate depreciation. Because only Ricardian households have access to financial market, the real exchange rate depend on their level of consumption through the risk sharing condition. Since the consumption of Ricardian agents declines it must follow an appreciation of the real exchange rate.

Monacelli and Perotti (2010) investigate the effect of alternative specifications of the utility function with non separability between consumption and leisure. They conclude that the functional form presented in Linnemann (2006) can explain the increase in private consumption and the real exchange rate depreciation. However, as noted in Bilbiie (2009), these results can be achieved only if either consumption or leisure are inferior goods. By contrast, the form of non separability introduced in Greenwood et al. (1988) can provide an explanation to the consumption-real exchange rate puzzle only for implausible values of the labour elasticity.

The deep-habit mechanism introduced in Ravn et al. (2012) enables the model to capture the initial increase in consumption and the real exchange rate depreciation, but it fails to reproduce the strong persistence of the depreciation.

Corsetti et al. (2012) explore the impact of spending reversals. They show that if higher government expenditure today implies lower expenditure in the future the model can predict the increase in consumption and the real exchange rate depreciation.

The remainder of the chapter is organized as follow. Section 2.2 presents the empirical evidences and compares my results with the previous literature. Section 2.3 presents a two-country economy model with LBD. Section 2.4 discusses the parameterization strategy followed for the baseline model. Section 2.5 uses a simplified model to illustrate the mechanism through which LBD affects the propagation mechanism of a government spending shock on the external sector of the economy and analyses the impulse responses for the complete model. Section 2.6 concludes.

2.2 Empirical evidences

2.2.1 VAR specification and identification

The effects of a government spending shock are estimated using a structural VAR model of the form:

$$AZ_t = c + \sum_{j=1}^p B_j Z_{t-j} + \varepsilon_t \quad (2.1)$$

where Z_t is a vector of observable variables, p is the lag length and ε_t is a vector of structural shocks. A and B_j are matrix of coefficients. My VAR model has seven variables: government spending (consumption and investment expenditure), GDP and taxes expressed in logs of real per capita terms; the nominal interest rate (3-Month Treasury Bill rate) and inflation (log differences in GDP deflator); a measure for capital utilization adjusted total factor productivity.¹ In order to economize on the degree of freedom I consider a seventh changing variable. For the latter I consider, in turn, private consumption (non durable goods and service expenditure) and investment (gross domestic investment and durable consumption) expressed in logs of real per capita terms; the log of the real exchange rate, defined so that an increase corresponds to a depreciation of the domestic currency; the trade balance scaled by GDP; the log of the real wage. The appendix provides more details on the data employed. The VAR includes four lags, a constant and a linear time trend. The sample runs from 1964:1 to 2006:4. The choice of the sample beginning is imposed by data availability, in particular with regard to the real exchange rate.

In order to recover the government spending structural shock, restrictions must be imposed on the matrix A . Following Blanchard and Perotti (2002), I assume that in the row of A associated with government expenditure all elements but the coefficient of government spending are zero. Thus, the identification strategy implies that all the variables in Z_t react immediately to government spending shocks, whereas government spending is predetermined

¹The series is provided by the Federal Reserve Bank of San Francisco and is based on Fernald (2009).

within the quarter and it is allowed to respond with one lag to structural innovations other than government spending. Under this assumption, the model can be estimated recursively and the reduced form residuals from a regression of government spending on its own lagged values and lagged values of other endogenous variables included in the model can be interpreted as structural shock to government spending.

2.2.2 Estimation results

Figure 2.1 displays impulse responses to government spending increase normalized to 1% of GDP. The solid line corresponds to the point estimates and the shaded area represents the 90% confidence interval obtained by bootstrap sampling based on 1,000 repetitions. The impulse responses for the first six variables are obtained from the VAR model that includes consumption as the seventh variable. Time on the horizontal axes is expressed in quarters. The responses of the nominal interest rate and inflation are measured as annualized percentage points deviation from the pre-shock path. Trade balance is expressed as percentage points change in the share of GDP relative to the pre-shock path. The remaining variables are expressed in percentage deviation from the pre-shock path.

The response of GDP, which can be interpreted as multiplier, on impact is statistically significant and is around 1. The level of output also displays a persistent increase in response to the shock.

The nominal interest rate display a not statistically significant decrease, whereas the initial fall in inflation in response to the government spending increase is significant. The same result has also been found in Canova and Pappa (2007), Edelberg et al. (1999), Fatás and Mihov (2001) and Mountford and Uhlig (2009). The point estimates for both variables are steadily below the pre-shock level.

After a non statistically significant increase on impact, the real wage hits its peak after about 5 periods rising by more than 1% respect to the pre-shock period. Similar results have been documented in Pappa (2009), Galí et al. (2007) and Perotti (2008).

Private consumption shows a significant, large and persistent increase and peaks around 10 quarters after the shock at about 1% above its pre-shock level. Similar results have been extensively documented in the literature. See, for example, Blanchard and Perotti (2002) and Fatás and Mihov (2001).

Also the response of investment is in line with previous studies. However, the VAR model does not provide an unambiguous clue of the effect on private investment of a change in government spending. The trade balance decreases of about 0.20 points of GDP and goes back to the pre-shock period only after 5 years. There is also a large and persistent depreciation of the real exchange rate. At its peak, around 4 years after the shock, the depreciation of the real exchange rate is about 3%. However, my results are not statistically significant. Analogous responses of the real exchange rate and the trade balance have been found in Monacelli and Perotti (2010), Ravn et al. (2012) and Corsetti et al. (2012). By contrast, Kim and Roubini (2008) find that the real exchange rate depreciates but the trade balance improves.

Finally, I also find evidence in support of a statistically significant increase in TFP. This result is consistent with previous contributions to the empirical literature. Early work by Evans (1992) finds a positive correlation between government spending and Solow residuals. Ramey and Shapiro (1998) show that an increase in military government spending raises labour productivity. Bachmann and Sims (2012) use a VAR approach to document the increase in TFP and to show that the increase is larger during recession.

2.3 The model

The model is based on a standard two-country new Keynesian DSGE model. The world economy is made up of two countries, referred to as H (Home or domestic) and F (Foreign). Home economy accounts for a fraction n of the global population normalized to unity. Each economy produces a country specific intermediate goods. A fixed fraction n of firms is located in Home, and the remaining firms $(n, 1]$ are located in Foreign. Intermediate goods are traded across borders. Non tradable final goods produced in each country are

a bundle of domestically produced and imported goods and can be used for consumption and investment.

The two economies are subjected to uncorrelated shocks but share the same preferences, technology and market structure.

While the law of one price (LOP) holds, home bias in preference yields the deviation from the purchasing power parity (PPP).

On the demand side, households provide labour and capital services only within the country they reside but have access to a complete set of contingent asset traded internationally. There exist frictions in both price and wage setting so that they can be adjusted only infrequently.

Finally, in what follows variables with " F " superscripts refer to the foreign economy, whereas variables without superscripts correspond to the domestic economy.

2.3.1 Final goods producers

Final goods M_t are bundles of domestically produced goods H_t and imported goods F_t . Final goods, which are not traded across borders, can be used for both consumption C_t and investment I_t . The final goods producer has the following CES aggregate function:

$$M_t = \left[[1 - (1 - n)\omega]^{\frac{1}{\sigma}} H_t^{\frac{\sigma-1}{\sigma}} + [(1 - n)\omega]^{\frac{1}{\sigma}} F_t^{\frac{\sigma-1}{\sigma}} \right]^{\frac{\sigma}{\sigma-1}} \quad (2.2)$$

where σ measures the substitutability between domestic and imported goods and $\omega \in [0, 1]$ defines the degree of home bias.

The bundles of domestically produced goods and imported goods are defined by:

$$H_t = \left[\left(\frac{1}{n} \right)^{\frac{\lambda_f}{1+\lambda_f}} \int_0^n H_t(j)^{\frac{1}{1+\lambda_f}} dj \right]^{1+\lambda_f} \quad (2.3)$$

$$F_t = \left[\left(\frac{1}{1-n} \right)^{\frac{\lambda_f}{1+\lambda_f}} \int_n^1 F_t(j)^{\frac{1}{1+\lambda_f}} dj \right]^{1+\lambda_f} \quad (2.4)$$

where $H_t(j)$ and $F_t(j)$ are intermediate goods produced respectively in country H and F ; λ_f measures the elasticity of substitution between intermediate goods produced within the same country.

Minimizing total expenditure subject to (2.2) yields the optimal allocation between domestically produced and imported goods:

$$H_t = (1 - (1 - n)\omega) \left(\frac{P_{H,t}}{P_{CPI,t}} \right)^{-\sigma} M_t \quad (2.5)$$

$$F_t = (1 - n)\omega \left(\frac{P_{F,t}}{P_{CPI,t}} \right)^{-\sigma} M_t \quad (2.6)$$

where $P_{CPI,t} = \left\{ [1 - (1 - n)\omega] (P_{H,t})^{(1-\sigma)} + [(1 - n)\omega] (P_{F,t})^{(1-\sigma)} \right\}^{\frac{1}{1-\sigma}}$ is the domestic consumer price index, $P_{H,t} = \left[\frac{1}{n} \int_0^n P_{H,t}(j)^{-\frac{1}{\lambda_f}} dj \right]^{-\lambda_f}$ is the domestically produced goods price index, $P_{F,t} = \left[\frac{1}{1-n} \int_n^1 P_{F,t}(j)^{-\frac{1}{\lambda_f}} dj \right]^{-\lambda_f}$ is a price index for imported goods expressed in term of domestic currency.

Given the total expenditure on domestically produced and imported goods, the optimal allocation within each type $j \in [0, 1]$ good is:

$$H_t(j) = \left(\frac{1}{n} \right) \left(\frac{P_{H,t}(j)}{P_{H,t}} \right)^{-\frac{1+\lambda_f}{\lambda_f}} H_t \quad (2.7)$$

$$F_t(j) = \left(\frac{1}{1-n} \right) \left(\frac{P_{F,t}(j)}{P_{F,t}} \right)^{-\frac{1+\lambda_f}{\lambda_f}} F_t \quad (2.8)$$

To simplify the analysis, I assume that government spending G_t is composed only of domestically produced goods.² Under this assumption the demand for an intermediate good domestically produced $Y_t^D(j)$ is:

$$Y_t^D(j) = nH_t(j) + (1 - n)H_t^F(j) + G_t(j) \quad (2.9)$$

where $G_t(j) = \left(\frac{P_{H,t}(j)}{P_{H,t}} \right)^{-\frac{1+\lambda_f}{\lambda_f}} G_t$; $H_t^F(j) = \left(\frac{1}{n} \right) \left(\frac{P_{H,t}^F(j)}{P_{H,t}^F} \right)^{-\frac{1+\lambda_f}{\lambda_f}} H_t^F$ denotes the demand from country F of domestically produced goods of type j ; $P_{H,t}^F =$

²The same assumption is for example used in Corsetti et al. (2012)

$\left[\frac{1}{n} \int_0^n P_{H,t}^F(j)^{-\frac{1}{\lambda_f}} dj \right]^{-\lambda_f}$ is a price index for goods produced in country H and expressed in terms of country F currency.

2.3.2 Intermediate goods producers

The intermediate good j is obtained using the technology common across all firms:

$$Y(j) = (K_t(j))^\alpha (N_t(j)X_t)^{(1-\alpha)} \quad (2.10)$$

where $0 < \alpha < 1$, $K_t(j)$ and $N_t(j)$ denote the physical capital and the homogeneous labour services used to produce the j^{th} good.

X_t denotes the average level of skills of labour suppliers which depends on aggregate hours worked in the past. Following Chang et al. (2002), skill accumulation is assumed to evolve according to:

$$X_t = X_{t-1}^{\rho_x} N_{t-1}^{\mu_n} \quad (2.11)$$

where $0 < \rho_x < 1$ and $\mu_n \geq 0$.

Throughout the rest of the chapter the expressions stock of knowledge and total factor productivity are equivalently used to indicate the level of skills.

It is worth noting that the assumption that skills are embodied in workers coupled with the fact that workers mobility is not allowed, rule out the hypothesis that LBD could leak from one country to the other. Changes in the level of productivity within each country depend only on the aggregate level of hours worked within the country.

The nominal wage W_t and the rental cost of capital R_t^K are given for the intermediate goods producers. Hence, cost minimization implies the same capital-to-labour ratio for all firms

$$\frac{K_t}{N_t} = \frac{\alpha}{1-\alpha} \frac{W_t}{R_t^K} \quad (2.12)$$

The marginal cost, common to all firms, is:

$$MC_t = \frac{W_t^{(1-\alpha)} R_t^K \alpha}{\alpha^\alpha (1-\alpha)^{(1-\alpha)} X_t^{(1-\alpha)}} \quad (2.13)$$

Following Calvo (1983) I assume that in every period a fraction of firms ζ_p cannot re-optimize their prices $P_{H,t}(j)$. In this case firms adjust their prices mechanically according to the rule:

$$P_{H,t}(j) = (\pi_{H,t-1})^{\iota_p} (\pi_H)^{1-\iota_p} \quad (2.14)$$

where $\pi_{H,t} = P_{H,t}/P_{H,t-1}$ and π_H is the steady-state inflation rate of domestically produced goods.

The fraction $(1 - \zeta_p)$ of firms able to re-optimize their price chose the new prices to solve:

$$\max_{P_{H,t}(j)^{new}} \mathbb{E}_t \left[\left(P_H(j)^{new} \left(\prod_{l=1}^s (\pi_{H,t-1+l})^{\iota_p} (\pi_H)^{1-\iota_p} \right) - MC_{t+s} \right) \sum_{s=0}^{\infty} (\zeta_p \beta)^s \Xi_{t+s} Y_{t+s}(j) \times \right] \quad (2.15)$$

subject to the demand function (2.9). The term $\beta^s \Xi_{t+s}$ is the current value of a future dollar expressed in consumption units.

Considering only a symmetric equilibrium where all firms choose the same price, the law of motion for the aggregate price is:

$$P_{H,t} = \left[(1 - \zeta_p) (P_{H,t}^{new})^{-\frac{1}{\lambda_f}} + \zeta_p ((\pi_{H,t-1})^{\iota_p} (\pi_H)^{1-\iota_p} P_{H,t-1})^{-\frac{1}{\lambda_f}} \right]^{\lambda_f} \quad (2.16)$$

2.3.3 Households

The objective function for the households $i \in [0, 1]$ is given by:

$$\mathbb{E}_t \sum_{s=0}^{\infty} \beta^s \left\{ \log(C_{t+s}(i) - hC_{t+s-1}(i)) - \frac{N_{t+s}^{1+\varphi}(i)}{1+\varphi} \right\} \quad (2.17)$$

where $C_t(i)$ is consumption, $N_t(i)$ denotes the quantity of the i^{th} type of labour service supplied; h is a parameter measuring the degree of consumption's habit and $\varphi > 0$ is the inverse of labour supply elasticity.

The household's budget constraint is:

$$\begin{aligned} P_{CPI,t+s}C_{t+s}(i) + P_{CPI,t+s}I_{t+s}(i) + B_{t+s}(i) &\leq R_{t+s-1}B_{t+s-1}(i) \\ + W_{t+s}(i)N_{t+s}(i) + [R_{t+s}^K u_{t+s}(i) - P_{CPI,t+s}a(u_{t+s}(i))] &\bar{K}_{t+s-1}(i) \\ + \Pi_{t+s} - T_{t+s}(i) & \end{aligned} \quad (2.18)$$

The right-hand side of the expression (2.18) corresponds to the household income net of the lump-sum taxes (or transfers) $T_t(i)$. Total income derives from different sources. The return from holding a one-period government bond is denoted by $R_t B_t(i)$. Labour income is $W_t(i)N_t(i)$. The term $[R_t^K u_t(i) - P_{CPI,t}a(u_t(i))]\bar{K}_{t-1}(i)$ indicates the net income from renting physical capital to intermediate firms. Following Smets and Wouters (2003) the effective capital rent to intermediate goods producer firms is $K_t(i) = u_t(i)\bar{K}_{t-1}(i)$, where $u_t(i)$ is the utilization rate of installed capital chosen by households. Households receive R_t^K for each unit of capital services supplied and pay a cost of utilization $a(u_t(i))$, expressed in term of the consumption good. Households also receive dividends Π_t from the imperfect competitive intermediate firms. Households allocate their income to consumption $C_t(i)$ and investment in both physical capital $I_t(i)$ and government bond $B_t(i)$.

As in Christiano et al. (2005) the capital accumulation evolves according to:

$$\bar{K}_t(i) = (1 - \delta)\bar{K}_{t-1}(i) + \left[1 - S\left(\frac{I_t(i)}{I_{t-1}(i)}\right)\right]I_t(i) \quad (2.19)$$

where δ is the depreciation rate, and $S(\cdot)$ is the cost of adjusting investment, with $S(1) = S'(1) = 0$ and $S''(1) > 0$.

2.3.4 Labour contractors and wage setting

Each household is a monopolistic supplier of differentiated labour services $N_t(i)$ to labour contractors. Labour contractors are perfect competitive firms.

They aggregate the differentiated labour services into an homogeneous labour service N_t hired by intermediate goods producers. The aggregation function is:

$$N_t = \left[\int_0^1 N_t(i)^{\frac{1}{1+\lambda_w}} di \right]^{1+\lambda_w} \quad (2.20)$$

where $\lambda_w > 0$ is a fixed parameter.

The demand for each type of labour service is derived from labour contractor profit maximization:

$$N_t(i) = \left(\frac{W_t(i)}{W_t} \right)^{-\frac{1+\lambda_w}{\lambda_w}} N_t \quad (2.21)$$

where $W_t = \left[\int_0^1 W_t(i)^{-\frac{1}{\lambda_w}} di \right]^{-\lambda_w}$ is the aggregate level of wages

Households face *à la* Calvo-style wage setting frictions. In each period the fraction ζ_w of households are unable to readjust their wage. In this case households set their wage according to:

$$W_t(i) = (\pi_{CPI,t-1})^{\iota_w} (\pi_{CPI})^{1-\iota_w} W_{t-1}(i) \quad (2.22)$$

Those households able to re-optimize their wage solve:

$$\max_{W_t^{new}} \mathbb{E}_t \sum_{s=0}^{\infty} \zeta_w^s \beta^s \left\{ -\frac{(N_{t+s}(i))^{1+\varphi}}{1+\varphi} \right\} \quad (2.23)$$

subject to (2.18), (2.21) and

$$W_{t+s}(i) = \prod_{l=1}^s (\pi_{CPI})^{(1-\iota_w)} (\pi_{CPI,t+l-1})^{\iota_w} W_t^{new} \quad (2.24)$$

Considering a symmetric equilibrium in which all households able to set a new wage chose the same level, wage evolution is defined as:

$$W_t = \left\{ (1 - \zeta_w) (W_t^{new})^{-\frac{1}{\lambda_w}} + \zeta_w \left[(\pi_{CPI})^{(1-\iota_w)} (\pi_{CPI,t-1})^{\iota_w} W_{t-1} \right]^{-\frac{1}{\lambda_w}} \right\}^{-\lambda_w} \quad (2.25)$$

2.3.5 The Term of Trade (TOT), the real exchange rate and the trade balance

The effective term of trade for the domestic economy is:

$$S_t = \frac{P_{F,t}}{P_{H,t}} \quad (2.26)$$

Let ξ_t denote the nominal exchange rate (i.e. the price of country F 's currency expressed in term of domestic currency). I assume that the law of one prices holds for any good j and hence $P_t(j) = \xi_t P_t^F(j)$.

The real exchange rate is defined as the ratio of the two countries' consumer price indices both expressed in domestic currency:

$$Q_t = \frac{\xi_t P_{CPI,t}^F}{P_{CPI,t}} \quad (2.27)$$

where $P_{CPI,t}^F$ is the consumer price index for the country F .

Finally, net export in term of domestic output and expressed as a fraction of steady state output are:

$$NX_t = \left(\frac{1}{Y} \right) \left(Y_t - \frac{P_{CPI,t}}{P_{H,t}} C_t - \frac{P_{CPI,t}}{P_{H,t}} I_t - \frac{P_{CPI,t}}{P_{H,t}} a(u_t) \bar{K}_{t-1} - G_t \right) \quad (2.28)$$

2.3.6 Government policies

The central bank sets the nominal interest rate R_t according to a Taylor rule that responds to CPI inflation and GDP growth:

$$\frac{R_t}{R} = \left(\frac{R_{t-1}}{R} \right)^{\rho_r} \left[\left(\frac{\pi_{CPI,t}}{\pi_{CPI}} \right)^{\phi_\pi} \left(\left(\frac{GDP_t}{GDP_{t-1}} \right)^{\phi_{gdp}} \right) \right] \quad (2.29)$$

where variables without time subscript denote steady state values. Similarly to Christiano et al. (2010) my definition of GDP_t does not consider the capital

utilization cost and is defined as:

$$GDP_t = \left(\frac{P_{H,t}}{P_{CPI,t}} \right)^{-\sigma} \left[\frac{(1 - (1 - n)\omega)(C_t + I_t) + (1 - n)\omega Q_t^\sigma (C_t^F + I_t^F)}{(1 - n)\omega Q_t^\sigma (C_t^F + I_t^F)} \right] + G_t \quad (2.30)$$

Government spending is financed either by issuing a domestic currency denominated bond or by a lump-sum tax. Therefore, the government budget constraint is:

$$P_{H,t}G_t + R_{t-1}B_{t-1} = T_t + B_t \quad (2.31)$$

Government sets the lump-sum tax following a simple feedback rule in order to prevent an explosive government debt.

Finally, government spending is defined by:

$$\ln G_t = (1 - \rho_g) \ln G + \rho_g \ln G_{t-1} + \varepsilon_t^g \quad (2.32)$$

where $\varepsilon_t^g \sim (0, 1)$.

2.3.7 Goods market clearing

The aggregate index for domestically produced goods is $Y_t = \left[\int_0^1 Y_t(j)^{\frac{1}{1+\lambda_f}} dj \right]^{1+\lambda_f}$. Using the definition of the nominal exchange rate and the equilibrium condition $Y_t(j) = Y_t(j)^D$, where demand is defined in (2.9), market clearing condition for the domestic economy is:

$$Y_t = \left(\frac{P_{H,t}}{P_{CPI,t}} \right)^{-\sigma} \times \left[\frac{(1 - (1 - n)\omega)(C_t + I_t + a(u_t) \bar{K}_{t-1}) + (1 - n)\omega Q_t^\sigma (C_t^F + I_t^F + a(u_t^F) \bar{K}_{t-1}^F)}{(1 - n)\omega Q_t^\sigma (C_t^F + I_t^F + a(u_t^F) \bar{K}_{t-1}^F)} \right] + G_t \quad (2.33)$$

Country F is a mirror economy of domestic country. Hence, its economy is described by a set of equations analogous to the equilibrium conditions described for country H . Note that when $n = 1$ the model corresponds to a closed economy model, whereas, for $n = 0$ the model collapses to a small open

economy where domestic economy has no effect on the foreign economy.

2.3.8 International risk sharing

Under the assumption of complete market, the risk sharing condition implies that the marginal utility of consumption, weighted by the real exchange rate should be equalized across countries:

$$\vartheta Q_t U_{c,t} = U_{c,t}^F \quad (2.34)$$

where ϑ is a constant which depends on the initial relative asset position. Given the symmetry between the two economies, it can be normalized to one without loss of generality. The intuition behind equation (2.34) is the following. Considering the RER as the relative price of a bundle of foreign consumption goods expressed in term of domestic one, a benevolent social planner would allocate consumption between foreign and domestic economy up to the point where the marginal utility of consumption across country is the same. If a complete set of state-contingent securities freely tradable across borders is available, the same equilibrium can also be achieved in a decentralized economy, even if the existence of some form of frictions generates a deviation from the PPP. The condition stated in equation (2.34) establishes a strong link between consumption and the RER and is the key features to understand the co-movement between the two variables.³

2.4 Parameterization

This section illustrates the parameter values employed for the model simulation. In what follows I consider a log-linearized approximation of the model around the deterministic steady state in which inflation is zero. Each period corresponds to a quarter. The responses of the trade balance is expressed as percentage points change in the share of GDP relative to the steady state level.

³Appendix B.4 shows how departing from the assumption of complete markets does not affect qualitatively the main results reported in the present chapter.

The responses of the nominal interest rate and inflation are measured as annualized percentage points deviation from the steady state level. The remaining variables are expressed in quarterly percentage deviation from the steady state level.

For the households preference parameters I choose conventional values and set the inverse of the elasticity of labour supply φ equal to 3. The discount factor β is equal to 0.9925 and corresponds to a steady state nominal interest of around 3% per year. The degree of habit in consumption h is equal to 0.75 as in Del Negro et al. (2007); λ_f and λ_w are both set equal to 0.05, implying that price and wage mark-ups in steady state are equal to 5%. I set $\alpha = 0.30$ to account for a labour share around 2/3. The capital depreciation rate δ is set to 0.025 to capture the investment-output ratio of 24%.

I set $\zeta_p = 0.75$ implying firms can change price on average once for year. This value is compatible with the results documented in Nakamura and Steinsson (2008) and in Bils and Klenow (2004). The wage stickiness parameter ζ_w is equal to 0.83, implying that the average wage duration is less than six quarters. Such degree of wage rigidity is in line with the results found in the most recent empirical literature.⁴ Following Christiano et al. (2010) I assume full wage indexation to past inflation ($\iota_w = 1$) and exclude price indexation ($\iota_p = 0$).

For the investment adjustment cost $S''(1)$ I rely on the value found in Smets and Wouters (2007) and I set it equal to 5.74. The capital utilization adjustment cost a'' is 0.038, which implies, as in Smets and Wouters (2007), that in response to 1% increase in the rental rate of capital the utilization rate rises by 0.85%.

The two parameters for the Learning-By-Doing, μ_n and ρ_x , are taken from Chang et al. (2002) and are equal to 0.111 and 0.798.

The autocorrelation coefficient for the government spending ρ_g is set to 0.90 as in Galí et al. (2007). The steady-state share of government spending

⁴Barattieri et al. (2010) find that on average the probability of a wage change is 18% per quarter, implying an expected duration of wage contracts of about 5.6 quarters and corresponding to ζ_w equal to 0.82. Gottschalk (2005) finds that the probabilities of wage constancy differ between males and females and is respectively equal to 53.7% and 46.5% per year. This would implies a value for ζ_w around 0.87. Schmitt-Grohé and Uribe (2011) find that the degree of downward inflexibility in nominal wages is around 1.

is assumed to be 0.20 corresponding to the post-war period average. For the specification of monetary policy I use conventional values and set $\phi_\pi = 1.5$, $\phi_{gdp} = 0.20$ and $\rho_r = 0.75$. The share of import ω is set to 0.15 to account for the average import share in US during the period considered around 10%. The substitutability between domestic and imported goods σ is set to 0.66 as in Corsetti et al. (2012). Country H 's size n is set equal to 0.20 to account for 20% of world production. Table 2.1 summarizes the values employed.⁵

2.5 Simulation results

Before turning to model simulation, I first illustrate the mechanisms through which introducing LBD can bring the response of the real exchange rate to a government spending shock closer in line with the data. As in chapter 1, to illustrate this mechanism I consider a simplified version of the model presented in section 2.3. The simulation results for the complete model are presented in the second part of the present section.

2.5.1 A simplified open economy model

First, there is no capital dynamic and intermediate goods producers have a linear production function ($\alpha = 0$ in equation (2.10)). I assume no habit in consumption ($h = 0$). Those households are not able to reoptimize their wages cannot index them to past inflation ($\iota_w = 0$). Finally, I assume monetary authority targets only current inflation ($\rho_r = \phi_{gdp} = 0$). In what follows ‘ \wedge ’

⁵In this chapter I calibrate rather than estimate the model for the following reasons. In a two-country medium scale DSGE model, because of the presence of the Foreign economy, the number of structural parameters to be estimated is magnified and could raise many identification issues. The literature has provided a solution to this problem within the framework of a small open economy where the foreign variables are modelled as exogenous shocks (see Adolfson et al. (2007)). However, given the relevance of the US economy it would be problematic to apply this approach to US data. On the other side, Lubik and Schorfheide (2006) use data for the US and the Euro area to estimate a small scale DSGE model where the two economies share the same technology and preference structure but policies, price setting and shocks hitting each economy are different. Despite this parsimonious approach offers a valid solution to deal with the identification problems, its ability to fit the data is open to question. I leave the exploration of these issues as a venue for further research.

denotes variables expressed in log-deviation from steady state.

First, consider the dynamic of the real exchange rate. From equation (2.34) one can obtain the following relationship between the real exchange rate and domestic and foreign consumption expressed in log-deviation from steady state:

$$\widehat{c}_t = \widehat{c}_t^F + \widehat{q}_t \quad (2.35)$$

Hence, under the assumption of international risk sharing condition, there exists a strong correlation between domestic consumption and the real exchange rate, and neglecting foreign consumption \widehat{c}_t^F , the same mechanism that affects the consumption dynamic also determines the real exchange rate behaviour.

To understand the dynamic of net exports consider that in this simplified version equation (2.28) can be rearranged as:

$$\widehat{nx}_t = \frac{C}{Y} (1 - n) \omega (2 - \omega) (\sigma - 1) \widehat{s}_t \quad (2.36)$$

The relationship between net export and the term of trade is not unique and depend on the size of σ . My baseline values imply a negative correlation between the two variables.⁶

Finally, consider that the term of trade is related to the real interest rate differential by the following relationship:

$$\widehat{s}_t = \mathbb{E}_t \sum_{k=0}^{\infty} [(\widehat{r}_{t+1}^F - \widehat{\pi}_{F,t+k+1}^F) - (\widehat{r}_{t+1} - \widehat{\pi}_{H,t+k+1})] \quad (2.37)$$

Figure 2.2 plots impulse responses for the simplified open economy. The responses are very similar to those presented for the closed economy in the first chapter. The main results emerging from this section is that the model replicates the real exchange rate empirical response. Furthermore, the increase in the term of trade, determined by the reduction of the domestic inflation, deteriorates the trade balance, in line with the empirical evidences.

⁶Mendoza (1995) documents that the correlation between the trade balance and the term of trade for the US is equal to -0.49

2.5.2 The complete medium size DSGE model

In this section I comment out the simulation results for the complete open economy model presented in section 2.3. Figure 2.3 compares the impulse responses of the full-fledged model with LBD (black solid line) and without LBD (red dashed line). The figure shows that with LBD also the fully specified model including capital accumulation and variable capital utilization generates a response of consumption, the real exchange rate, wages and TFP of the same sign of the empirical evidences provided in section 2.2.⁷ Indeed, for the richer model specification, differently from the simplified version presented in the section 2.5, these responses exhibit an higher persistence, improving the ability of the model to reproduce results in line with the empirical evidences. For consumption and the real exchange rate the fully specified model also captures the humped-shaped responses characterizing the VAR model. Differently from the simplified model, the trade balance shows a more persistent deterioration, bringing the predictions closer in line with the empirical results. In fact, the full-fledged model predicts a higher increase in consumption which boosts the domestic demand and generates a worsening of the trade balance. Thus, the model offers support to the "twin-deficit" hypothesis. These effects derives from the larger and long-lasting decrease in the long-term real interest rate occurring in the full-fledged model, which is the key mechanism from which the other results presented in the chapter derive.

As already discussed in chapter 1 the key feature determining these results is the increase in TFP derived from the endogenous increase in the stock of knowledge through the LBD mechanism. Without LBD a government spending would cause a counterfactual decrease of private consumption and through the international risk sharing condition an appreciation of the real exchange rate.

Compared to the the deep-habit mechanism introduced in Ravn et al. (2012) the model in this chapter is able to replicate the persistent depreci-

⁷Similarly to the data employed in the VAR analysis presented in section 2.2, the definition of TFP is based on a capital utilization adjusted TFP measure. Hence, the TFP level in my model coincides with the stock of knowledge X_t as defined in the equation 2.11.

ation of the RER, whereas their model is only able to replicate the initial response of the RER to a government spending shock but cannot mimic the persistence of the response.

The spending reversal mechanism proposed in Corsetti et al. (2012), while delivers results for consumption and the RER qualitatively in line with the data, similarly to Ravn et al. (2012) cannot generate the concomitant increase in productivity observed in the data.

2.6 Conclusion

This chapter contributes by an empirical and theoretical analysis to the ongoing debate on the short-run effect of the fiscal policy stance and focus on the impact of government spending on the real exchange rate.

The main result of the present chapter is to show that including a Learning-By-Doing mechanism in an open economy version of an otherwise standard new Keynesian DSGE model enables the model to replicate the real exchange rate depreciation observed in the data. This result depends on the ability of the model proposed to match the positive response of consumption. In fact, as already discussed in chapter 1, the LBD mechanism makes the model able to generate a positive response of consumption to a government spending increase. Under the assumption of complete markets, the risk sharing condition implies a strong correlation between consumption and real exchange rate. Hence the increase in domestic consumption results in a depreciation of the real exchange rate.

Table 2.1: Parameter values used in the baseline medium-size DSGE model

Parameter		Value	Target/Source
φ	inverse labour supply elasticity	3	conventional value
β	discount factor	0.9925	annualized interest rate: 3%
h	consumption habit	0.75	Del Negro et al. (2007)
λ_f	price mark-up	0.05	steady state wage mark-up: 5%
λ_w	wage mark-up	0.05	steady state wage mark-up: 5%
α	capital share	0.30	Labour share: 2/3
δ	capital depreciation rate	0.025	Investment output ratio: 0.24
ζ_p	probability of price fixed	0.75	Average price duration: 4 qrts
ζ_w	probability of wage fixed	0.83	Average wage duration: 6 qrts
ι_w	degree of wage indexation	1	full indexation to past inflation
ι_p	degree of price indexation	0	no indexation to past inflation
S''	investment adjustment cost	5.74	Smets and Wouters (2007)
a''	capital utilization cost	0.038	Smets and Wouters (2007)
μ_n	LBD: hours impact	0.111	Chang et al. (2002)
ρ_x	LBD: auto-correlation	0.798	Chang et al. (2002)
ρ_g	auto-correlation spending	0.90	Galí et al. (2007)
$\frac{G}{GDP}$	spending to GDP ratio	0.20	sample average
ϕ_π	Monetary rule: inflation	1.5	standard value
ϕ_{gdp}	Monetary rule: output growth	0.20	standard value
ρ_r	Monetary rule: smoothing	0.75	standard value
ω	degree of openness	0.15	Import-output ratio: 10%
σ	trade elasticity	0.66	Corsetti et al. (2012)
n	H economy size	0.20	Share of U.S. GDP in world output

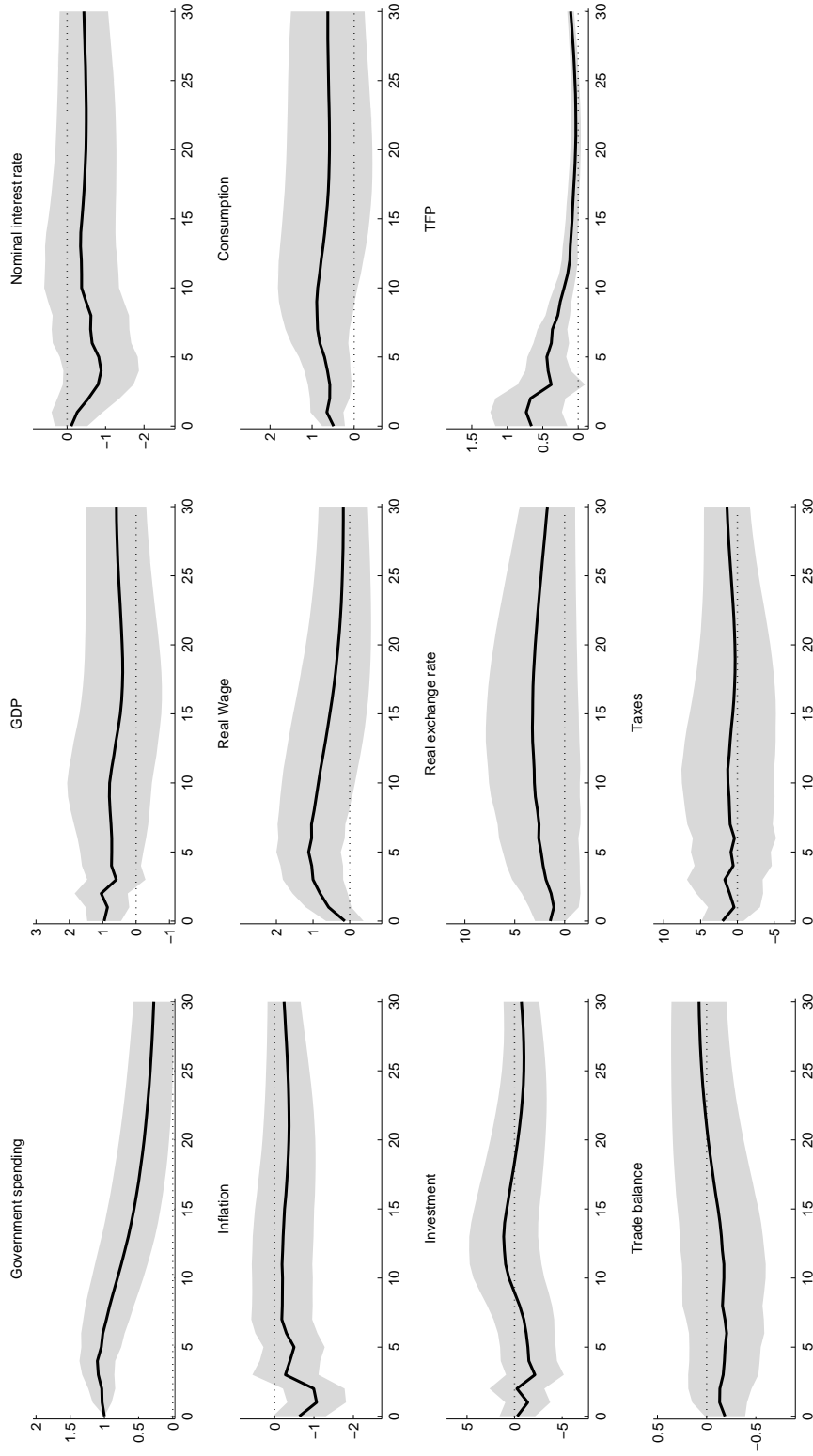


Figure 2.1: VAR responses. This figure shows impulse responses to a government spending shock equal to 1% of GDP. The solid lines are the actual impulse responses. The shaded grey areas are 90% confidence intervals obtained by bootstrap sample. The horizontal axis indicate quarters. The trade balance is expressed as percentage points change in the share of GDP relative to the pre-shock path; nominal interest rate and inflation are measured as annualized percentage points deviation from the pre-shock level; the remaining variables are expressed in percentage deviation from the pre-shock level.

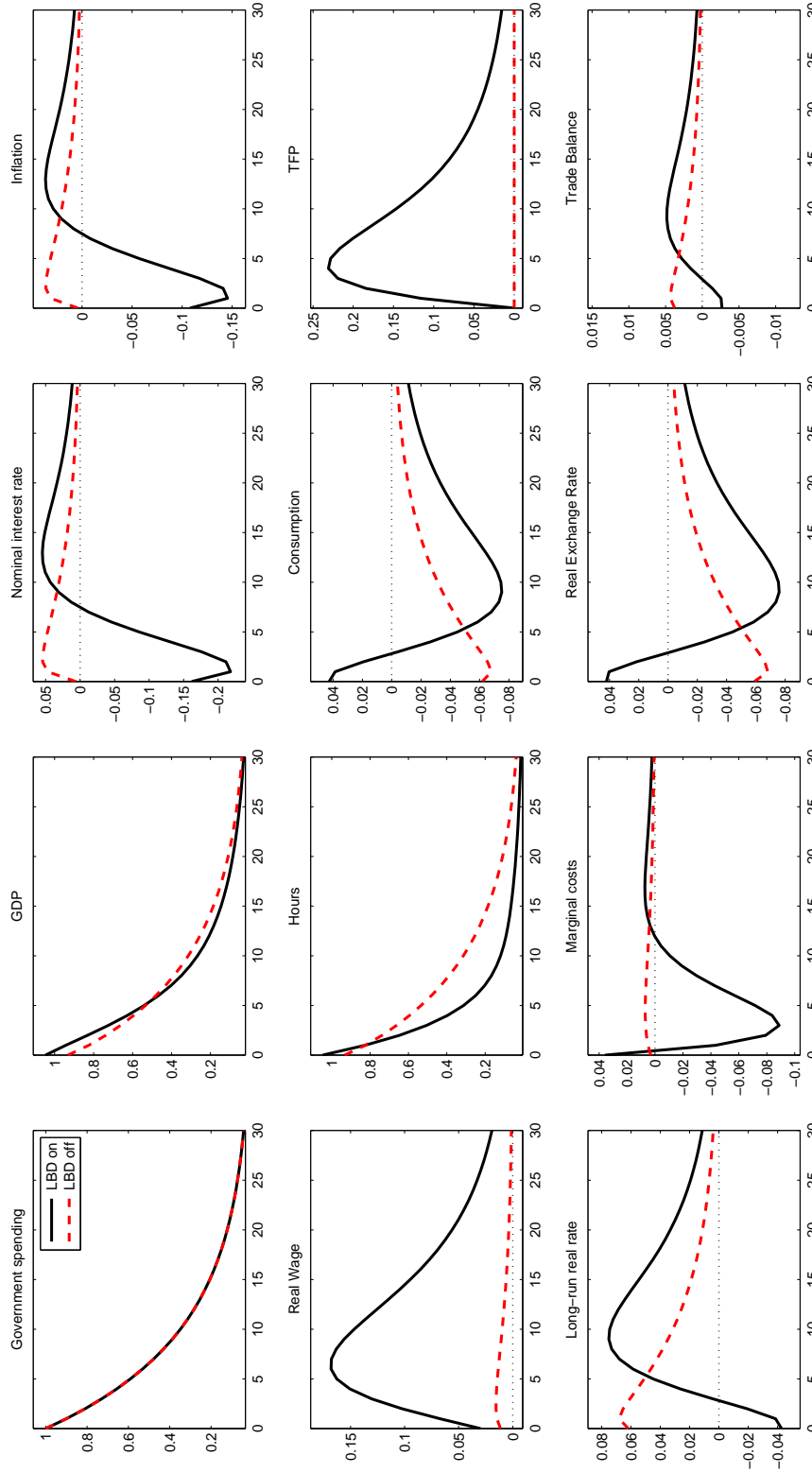


Figure 2.2: DSGE responses for the simplified open economy with and without LBD. This figure shows impulse responses to a government spending shock equal to 1% of GDP for the simplified open economy with LBD (black solid line) and without LBD (dashed red line). Notes: Responses are expressed in percentage deviation from steady state with the exception of the nominal interest rate and inflation which are measured as annualized percentage points deviation from steady state and the trade balance which is measured as percentage points change in the share of GDP relative to the steady state level.

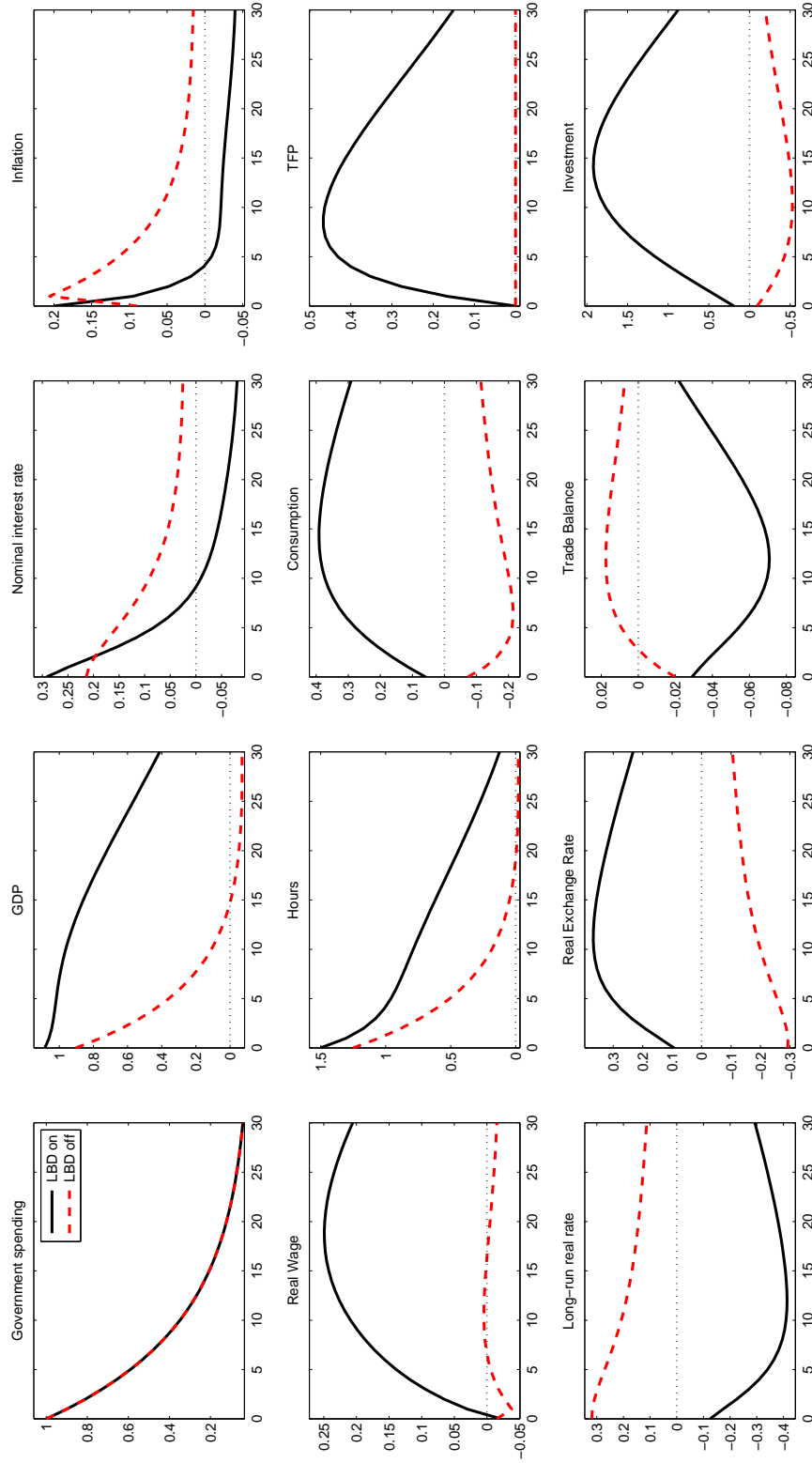


Figure 2.3: DSGE responses for the full-fledged open economy with and without LBD. This figure shows impulse responses to a government spending shock equal to 1% of GDP for the full-fledged open economy with LBD (black solid line) and without LBD (dashed red line). Notes: see notes fig. 2.2.

APPENDIX B

Appendix to chapter 2

B.1 Data

This section describes more in details data employed in the estimation of the VAR model presented in chapter 2.

Population: Civilian Noninstitutional Population (CNP16OV). Source: FRED, Federal Reserve Bank of ST. Louise. Note: average of monthly figures.

GDP deflator: Implicit Price Deflator for Gross Domestic Product, Table 1.1.9. line 1. Source : Bureau of Economic Analysis (BEA); Note: Index numbers, 2009=100. Seasonally adjusted.

GDP: Gross Domestic Product, Table 1.1.5 line 1. Source : Bureau of Economic Analysis (BEA); Note: Seasonally adjusted at annual rates.

Government spending: Government consumption expenditures and gross investment, Table 1.1.5 line 21. Source: Bureau of Economic Analysis (BEA). Note: Seasonally adjusted at annual rates.

Consumption: non-durable goods +services, Table 1.1.5 lines 5 and 6. Source: Bureau of Economic Analysis (BEA); Note: Seasonally adjusted at annual rates.

Interest rate: 3-Month Treasury Bill: Secondary Market Rate (TB3MS). Source: FRED, Federal Reserve Bank of ST. Louise. Note: average of monthly figures. Not Seasonally Adjusted.

Inflation: log differences in the Implicit Price Deflator for Gross Domestic Product.

Taxes: Current receipts, Table 3.1. line 1, minus Current transfer payments, Table 3.1. line 17, minus Interest payments, Table 3.1. line 22. Source: Bureau of Economic Analysis (BEA); Note: Seasonally adjusted at annual rates.

Investment: Gross private domestic investment, Table 1.1.5 line 7 plus Durable goods, Table 1.1.5 line 4. Source: Bureau of Economic Analysis (BEA); Note: Seasonally adjusted at annual rates.

Real exchange rate: Effective exchange rate, narrow index comprising 27 economies. Source: Bank of International Settlements. Note: Data are converted to quarterly frequencies by averaging monthly figures. In the original data an increase corresponds to an appreciation of the domestic currency. In order to enhance the comparability with the DSGE model, I convert the data so that an increase corresponds to a depreciation.

Total factor productivity: Utilization-adjusted TFP. Source: Federal Reserve Bank of San Francisco.

Wages: Nonfarm Business Sector: Compensation Per Hour (COMPNFB). Source: FRED, Federal Reserve Bank of ST. Louise. Note: Index numbers, 2009=100. Seasonally adjusted.

B.2 Model derivation

The aim of this section is to provide some technical details on derivation of model presented in chapter 2. In particular I illustrate the derivation of the market clearing conditions for both countries and the first order conditions that describe the model equilibrium.

B.2.1 Goods Market clearing condition

In this part I illustrate how to derive the market clearing condition for both countries. I start from defining the demand for imported and domestically

produced goods as well as the demand for each j -type good.

Country H 's demand for domestically produced goods H_t and imported goods F_t can be derived by minimizing total expenditure subject to the final good aggregate function (2.2):

$$\min_{H_t, F_t} P_{H,t} H_t + P_{F,t} F_t \quad (\text{B.1})$$

s.to

$$M_t = \left[[1 - (1 - n) \omega]^{\frac{1}{\sigma}} H_t^{\frac{\sigma-1}{\sigma}} + [(1 - n) \omega]^{\frac{1}{\sigma}} F_t^{\frac{\sigma-1}{\sigma}} \right]^{\frac{\sigma}{\sigma-1}} \quad (\text{B.2})$$

Combining first order conditions yields:

$$\frac{H_t}{F_t} = \frac{1 - (1 - n) \omega}{(1 - n) \omega} \left(\frac{P_{H,t}}{P_{F,t}} \right)^{-\sigma} \quad (\text{B.3})$$

Collecting $F_t^{\frac{\sigma-1}{\sigma}}$ in the constraint (B.2) and using (B.3) yields:

$$M_t = F_t \left\{ [1 - (1 - n) \omega] \left[\frac{1}{(1 - n) \omega} \right]^{\frac{\sigma-1}{\sigma}} \left(\frac{P_{H,t}}{P_{F,t}} \right)^{(1-\sigma)} + [(1 - n) \omega]^{\frac{1}{\sigma}} \right\}^{\frac{\sigma}{\sigma-1}} \quad (\text{B.4})$$

By collecting $\left[\frac{1}{(1-n)\omega} \right]^{\frac{\sigma-1}{\sigma}} \left(\frac{1}{P_{F,t}} \right)^{(1-\sigma)}$ after some algebra expression above becomes:

$$M_t = F_t \left[\frac{1}{(1 - n) \omega} \right] \left(\frac{1}{P_{F,t}} \right)^{-\sigma} \left\{ [1 - (1 - n) \omega] P_{H,t}^{(1-\sigma)} + P_{F,t}^{(1-\sigma)} [(1 - n) \omega] \right\}^{\frac{\sigma}{\sigma-1}} \quad (\text{B.5})$$

Using the definition of CPI inflation and solving for F_t yields the aggregate demand of imported goods corresponding to equation (2.6) in the main text:

$$F_t = (1 - n) \omega \left(\frac{P_{F,t}}{P_{CPI,t}} \right)^{-\sigma} M_t \quad (\text{B.6})$$

The demand for domestically produced goods H_t , equation (2.5) in the main text, can be obtained using equation above to substitute for F_t into (B.3):

$$H_t = (1 - (1 - n)\omega) \left(\frac{P_{H,t}}{P_{CPI,t}} \right)^{-\sigma} M_t \quad (\text{B.7})$$

The demand for $H_t(j)$, the domestically produced good of type j demanded by country H , can be derived by minimizing the expenditure on $H_t(j)$ subject to the definition of the aggregate domestically produced good (2.3):

$$\min_{H_t(j)} P_{H,t}(j) H_t(j) \quad (\text{B.8})$$

s.t

$$H_t = \left[\left(\frac{1}{n} \right)^{\frac{\lambda_f}{1+\lambda_f}} \int_0^n H_t(j)^{\frac{1}{1+\lambda_f}} dj \right]^{1+\lambda_f} \quad (\text{B.9})$$

Let Γ be the Lagrangian multiplier associated with the constraint in (B.9) first order condition is:

$$P_{H,t}(j) = \Gamma \left(\frac{1}{n} \right)^{\frac{\lambda_f}{1+\lambda_f}} \frac{1}{1+\lambda_f} H_t(j)^{-\frac{\lambda_f}{1+\lambda_f}} \quad (\text{B.10})$$

Solving for $H_t(j)$ and plugging into (B.9) yields:

$$H_t = \left[\frac{1}{n} \Gamma^{\frac{1}{\lambda_f}} \left(\frac{1}{1+\lambda_f} \right)^{\frac{1}{\lambda_f}} \int_0^n P_{H,t}(j)^{-\frac{1}{\lambda_f}} dj \right]^{1+\lambda_f} \quad (\text{B.11})$$

Solving for Γ and using the domestically produced aggregate price definition yields:

$$\Gamma = H_t^{\frac{\lambda_f}{1+\lambda_f}} (1+\lambda_f) P_{H,t} \quad (\text{B.12})$$

Plugging back into (B.10) and rearranging gives:

$$H_t(j) = \frac{1}{n} \left(\frac{P_{H,t}(j)}{P_{H,t}} \right)^{-\frac{1+\lambda_f}{\lambda_f}} H_t \quad (\text{B.13})$$

which correspond to equation (2.7) in the main text.

The demand for the j -type good produced in the foreign country $F_t(j)$ can

be derived in a similar manner by minimizing:

$$\min_{F_t(j)} P_{F,t}(j) F_t(j) \quad (\text{B.14})$$

s.t

$$F_t = \left[\left(\frac{1}{1-n} \right)^{\frac{\lambda_f}{1+\lambda_f}} \int_n^1 F_t(j)^{\frac{1}{1+\lambda_f}} dj \right]^{1+\lambda_f} \quad (\text{B.15})$$

Therefore the optimal allocation for $F_t(j)$, as in equation (2.8), is

$$F_t(j) = \frac{1}{1-n} \left(\frac{P_{F,t}(j)}{P_{F,t}} \right)^{-\frac{1+\lambda_f}{\lambda_f}} F_t \quad (\text{B.16})$$

Under the assumption that government spending in country H is allocated only to goods domestically produced, the government's demand for the j -type good is:

$$G_t(j) = \left(\frac{P_{H,t}(j)}{P_{H,t}} \right)^{-\frac{1+\lambda_f}{\lambda_f}} G_t \quad (\text{B.17})$$

Similarly, country F 's demand for good H_t^F produced in country H and for good F_t^F produced in country F , can be obtained by minimizing total expenditure subject to the definition of the bundle of final goods for the foreign economy equivalent to (2.2):

$$\min_{H_t^F, F_t^F} P_{H,t}^F H_t^F + P_{F,t}^F F_t^F \quad (\text{B.18})$$

s.to

$$M_t^F = \left[(n\omega)^{\frac{1}{\sigma}} (H_t^F)^{\frac{\sigma-1}{\sigma}} + (1-n\omega)^{\frac{1}{\sigma}} (F_t^F)^{\frac{\sigma-1}{\sigma}} \right]^{\frac{\sigma}{\sigma-1}} \quad (\text{B.19})$$

Solving the optimization problem stated above yields the demand for H_t^F and F_t^F :

$$H_t^F = n\omega \left(\frac{P_{H,t}^F}{P_{CPI,t}^F} \right)^{-\sigma} M_t^F \quad (\text{B.20})$$

$$F_t^F = (1 - n\omega) \left(\frac{P_{F,t}^F}{P_{CPI,t}^F} \right)^{-\sigma} M_t^F \quad (\text{B.21})$$

The demand for the j -type good produced in country H can be derived solving the expenditure problem subject to the definition of country F 's aggregate demand for goods produced in country H :

$$\min_{H_t^F(j)} P_{H,t}^F(j) H_t^F(j) \quad (\text{B.22})$$

s.t

$$H_t^F = \left[\left(\frac{1}{n} \right)^{\frac{\lambda_f}{1+\lambda_f}} \int_0^n H_t^F(j)^{\frac{1}{1+\lambda_f}} dj \right]^{1+\lambda_f} \quad (\text{B.23})$$

The final expression for the demand for good j produced in country H is

$$H_t^F(j) = \frac{1}{n} \left(\frac{P_{H,t}^F(j)}{P_{H,t}^F} \right)^{-\frac{1+\lambda_f}{\lambda_f}} H_t^F \quad (\text{B.24})$$

Similarly country F 's demand for goods $F_t^F(j)$ can be derived by solving:

$$\min_{F_t^F(j)} P_{F,t}^F(j) F_t^F(j) \quad (\text{B.25})$$

s.t

$$F_t^F = \left[\left(\frac{1}{1-n} \right)^{\frac{\lambda_f}{1+\lambda_f}} \int_n^1 F_t^F(j)^{\frac{1}{1+\lambda_f}} dj \right]^{1+\lambda_f} \quad (\text{B.26})$$

Thus, the demand of the j -type good produced in country F is:

$$F_t^F(j) = \frac{1}{1-n} \left(\frac{P_{F,t}^F(j)}{P_{F,t}^F} \right)^{-\frac{1+\lambda_f}{\lambda_f}} F_t^F \quad (\text{B.27})$$

Assuming that government spending in country F is allocated only to goods produced in the foreign country, country F government's demand for j -type

good is:

$$G_t^F(j) = \left(\frac{P_{F,t}^F(j)}{P_{F,t}^F} \right)^{-\frac{1+\lambda_f}{\lambda_f}} G_t^F \quad (\text{B.28})$$

To derive the market clearing condition for country H plug (B.7), (B.13), (B.17), (B.20) and (B.24), into (2.9):

$$\begin{aligned} Y_t^D(j) &= \left(\frac{P_{H,t}(j)}{P_{H,t}} \right)^{-\frac{1+\lambda_f}{\lambda_f}} (1 - (1-n)\omega) \left(\frac{P_{H,t}}{P_{CPI,t}} \right)^{-\sigma} M_t \\ &\quad + (1-n)\omega \left(\frac{P_{H,t}^F(j)}{P_{H,t}^F} \right)^{-\frac{1+\lambda_f}{\lambda_f}} \left(\frac{P_{H,t}^F}{P_{CPI,t}^F} \right)^{-\sigma} M_t^F \\ &\quad + \left(\frac{P_{H,t}(j)}{P_{H,t}} \right)^{-\frac{1+\lambda_f}{\lambda_f}} G_t \end{aligned} \quad (\text{B.29})$$

Note that from the law of one price follows that $P_{H,t} = \xi_t P_{H,t}^F$. Hence, equation above can be written as:

$$\begin{aligned} Y_t^D(j) &= \left(\frac{P_{H,t}(j)}{P_{H,t}} \right)^{-\frac{1+\lambda_f}{\lambda_f}} (1 - (1-n)\omega) \left(\frac{P_{H,t}}{P_{CPI,t}} \right)^{-\sigma} M_t \\ &\quad + (1-n)\omega \left(\frac{P_{H,t}(j)}{P_{H,t}} \right)^{-\frac{1+\lambda_f}{\lambda_f}} \left(\frac{P_{H,t}}{\xi_t P_{CPI,t}^F} \right)^{-\sigma} M_t^F \\ &\quad + \left(\frac{P_{H,t}(j)}{P_{H,t}} \right)^{-\frac{1+\lambda_f}{\lambda_f}} G_t \end{aligned} \quad (\text{B.30})$$

Divide and multiply the second term on the RHS by $P_{CPI,t}$ and rearranging yields:

$$\begin{aligned} Y_t^D(j) &= \left(\frac{P_{H,t}(j)}{P_{H,t}} \right)^{-\frac{1+\lambda_f}{\lambda_f}} \times \\ &\quad \left\{ \left(\frac{P_{H,t}}{P_{CPI,t}} \right)^{-\sigma} \left[(1 - (1-n)\omega) M_t + (1-n)\omega \left(\frac{P_{CPI,t}}{\xi_t P_{CPI,t}^F} \right)^{-\sigma} M_t^F \right] + G_t \right\} \end{aligned} \quad (\text{B.31})$$

Using the definition of the real exchange rate (2.27) the total demand for the j -type good produced in country H is:

$$Y_t^D(j) = \left(\frac{P_{H,t}(j)}{P_{H,t}} \right)^{-\frac{1+\lambda_f}{\lambda_f}} \times \left\{ \left(\frac{P_{H,t}}{P_{CPI,t}} \right)^{-\sigma} \left[\frac{(1 - (1-n)\omega) M_t + (1-n)\omega Q_t^\sigma M_t^F}{(1-n)\omega Q_t^\sigma M_t^F} \right] + G_t \right\} \quad (\text{B.32})$$

As in the main text, define the aggregate output index for country H as:

$$Y_t = \left(\frac{1}{n} \int_0^n Y_t(j)^{\frac{1}{1+\lambda_f}} dj \right)^{1+\lambda_f} \quad (\text{B.33})$$

Plugging (B.32) into equation above and simplifying yields:

$$Y_t = \left\{ \left(\frac{P_{H,t}}{P_{CPI,t}} \right)^{-\sigma} P_{H,t}^{\frac{1+\lambda_f}{\lambda_f}} \left[(1 - (1-n)\omega) M_t + (1-n)\omega Q_t^\sigma M_t^F \right] + G_t \right\} \times \left[\frac{1}{n} \int_0^n P_{H,t}(j)^{-\frac{1}{\lambda_f}} dj \right]^{1+\lambda_f} \quad (\text{B.34})$$

Substituting the definition of aggregate domestically produced price index, equation above simplifies to:

$$Y_t = \left(\frac{P_{H,t}}{P_{CPI,t}} \right)^{-\sigma} \left[(1 - (1-n)\omega) M_t + (1-n)\omega Q_t^\sigma M_t^F \right] + G_t \quad (\text{B.35})$$

Similarly, define total demand for the j -type good produced in country F as:

$$Y_t^{D,F}(j) = nF_t(j) + (1-n)F_t^F(j) + G_t^F(j) \quad (\text{B.36})$$

Plug (B.6), (B.16), (B.21), (B.27) and (B.28) into equation above:

$$\begin{aligned}
Y_t^{D,F}(j) = & n\omega \left(\frac{P_{F,t}(j)}{P_{F,t}} \right)^{-\frac{1+\lambda_f}{\lambda_f}} \left(\frac{P_{F,t}}{P_{CPI,t}} \right)^{-\sigma} M_t \\
& + (1-n\omega) \left(\frac{P_{F,t}^F(j)}{P_{F,t}^F} \right)^{-\frac{1+\lambda_f}{\lambda_f}} \left(\frac{P_{F,t}^F}{P_{CPI,t}^F} \right)^{-\sigma} M_t^F \\
& + \left(\frac{P_{F,t}^F(j)}{P_{F,t}^F} \right)^{-\frac{1+\lambda_f}{\lambda_f}} G_t^F
\end{aligned} \tag{B.37}$$

Applying the law of one price, using the definition of real exchange rate and rearranging yields:

$$\begin{aligned}
Y_t^{D,F}(j) = & \left(\frac{P_{F,t}^F(j)}{P_{F,t}^F} \right)^{-\frac{1+\lambda_f}{\lambda_f}} \\
& \times \left\{ \left(\frac{P_{F,t}^F}{P_{CPI,t}^F} \right)^{-\sigma} [n\omega Q_t^{-\sigma} M_t + (1-n\omega) M_t^F] + G_t^F \right\}
\end{aligned} \tag{B.38}$$

Define the aggregate output index for country F as:

$$Y_t^F = \left(\frac{1}{1-n} \int_n^1 Y_t^F(j)^{\frac{1}{1+\lambda_f}} dj \right)^{1+\lambda_f} \tag{B.39}$$

Put (B.38) into equation above:

$$\begin{aligned}
Y_t^F = & \left\{ \left(\frac{P_{F,t}^F}{P_{CPI,t}^F} \right)^{-\sigma} P_{F,t}^F^{\frac{1+\lambda_f}{\lambda_f}} [n\omega Q_t^{-\sigma} M_t + (1-n\omega) M_t^F] + G_t^F \right\}^{\frac{1}{1+\lambda_f}} \times \\
& \left[\frac{1}{1-n} \int_0^n P_{F,t}^F(j)^{-\frac{1}{\lambda_f}} dj \right]^{1+\lambda_f}
\end{aligned} \tag{B.40}$$

Finally, using the definition of aggregate price index for goods produced in country F yields the aggregate goods market clearing condition for country F :

$$Y_t^F = \left(\frac{P_{F,t}^F}{P_{CPI,t}^F} \right)^{-\sigma} [n\omega Q_t^{-\sigma} M_t + (1 - n\omega) M_t^F] + G_t^F \quad (\text{B.41})$$

B.2.2 First order conditions

In this part I state the first order conditions describing the model equilibrium. Unless otherwise specified, the symbol “ \sim ” denotes variables expressed in real term using the consumer price index P_{CPI} . I focus on country H . A similar approach can be easily extended to country F .

Households.

In equilibrium all households make the same decision, therefore without loss of generality I drop the i index. Households first order conditions respect to bond holding B_t , consumption C_t , investment I_t , capital \bar{K}_t and capital utilization u_t are:

$$\lambda_t^I \mathbb{E}_t [\pi_{CPI,t+1}] = \beta \mathbb{E}_t [\lambda_{t+1}^I] R_t \quad (\text{B.42})$$

$$\lambda_t^I = \frac{1}{(C_t - hC_{t-1})} - \frac{h\beta}{(\mathbb{E}_t [C_{t+1}] - hC_t)} \quad (\text{B.43})$$

$$\lambda_t^I = \lambda_t^K \left[1 - S \left(\frac{I_t}{I_{t-1}} \right) - S' \left(\frac{I_t}{I_{t-1}} \right) \frac{I_t}{I_{t-1}} \right] + \beta \mathbb{E}_t [\lambda_{t+1}^K] \left[S' \left(\frac{\mathbb{E}_t [I_{t+1}]}{I_t} \right) \left(\frac{\mathbb{E}_t [I_{t+1}]}{I_t} \right)^2 \right] \quad (\text{B.44})$$

$$\lambda_t^K = \beta \mathbb{E}_t [\lambda_{t+1}^I] \left(\mathbb{E}_t [\tilde{R}_{t+1}^k u_{t+1}] - a(\mathbb{E}_t [u_{t+1}]) \right) + \beta (1 - \delta) \mathbb{E}_t [\lambda_{t+1}^K] \quad (\text{B.45})$$

$$\tilde{R}_t^k = a'(u_t) \quad (\text{B.46})$$

where $\lambda_t^I \equiv P_{CPI,t} \bar{\lambda}_t^I$ and $\bar{\lambda}_t^I$ and λ_t^K are the multipliers associated respectively to the budget constraint (2.18) and the capital evolution constraint (2.19).

The first order condition for the wage setting problem, after some straightforward algebra, can be written as:

$$\mathbb{E}_t \sum_{s=0}^{\infty} \zeta_w^s \beta^s \left[\left(X_{t,s}^W W_t^{rel} \frac{\tilde{W}_t}{\tilde{W}_{t+s}} \right)^{-\frac{1+\lambda_w}{\lambda_w}} N_{t+s} \right] \lambda_{t+s}^I \times \left\{ (1 + \lambda_w) \left(X_{t,s}^W W_t^{rel} \frac{\tilde{W}_t}{\tilde{W}_{t+s}} \right)^{-\frac{(1+\lambda_w)\varphi}{\lambda_w}} \frac{\{N_{t+s}\}^\varphi}{\lambda_{t+s}^I} - X_{t,s}^W W_t^{rel} \tilde{W}_t \right\} = 0 \quad (\text{B.47})$$

where $X_{t,s}^W \equiv \frac{\prod_{l=1}^s (\pi_{CPI})^{(1-i_w)} (\pi_{CPI,t+l-1})^{i_w}}{\prod_{l=1}^s \pi_{CPI,t+l}}$ and $W_t^{rel} \equiv \frac{\tilde{W}_t^{new}}{\tilde{W}_t}$ is the relative wage

chosen by those households that are allowed to re-optimize their wage respect to the level of wages at time t . Wage evolution defined in (2.25) can be expressed in term of relative wage:

$$\left(\tilde{W}_t \right)^{-\frac{1}{\lambda_w}} = (1 - \zeta_w) \left(W_t^{rel} \tilde{W}_t \right)^{-\frac{1}{\lambda_w}} + \zeta_w \left[\frac{(\pi_{CPI})^{(1-i_w)} (\pi_{CPI,t-1})^{i_w}}{\pi_{CPI,t}} \tilde{W}_{t-1} \right]^{-\frac{1}{\lambda_w}} \quad (\text{B.48})$$

Firms

A firm resetting its price in period t will seek to maximize the current value of its dividend conditional on that price being effective:

$$\max_{P_{H,t+s}^{new}(j)} \mathbb{E}_t \sum_{s=0}^{\infty} (\zeta_p)^s \Xi_{t,t+s} \{ [P_{H,t+s}(j) - MC_{t+s}] Y_{t+s}(j) \} \quad (\text{B.49})$$

subject to the total demand for the j -type good produced in country H expressed in (B.32) and to the price indexation scheme:

$$P_{H,t+s}(j) = P_{H,t}^{new}(j) \prod_{l=1}^s (\pi_H)^{(1-\iota_p)} (\pi_{H,t+l-1})^{\iota_p} \quad (\text{B.50})$$

By plugging (B.32) and (B.50) into (B.49) and considering only a symmetric equilibrium where all firm chose the same price ($P_{H,t}^{new}(j) = P_{H,t}^{new}$) the price setting problem can be written as:

$$\max_{P_{H,t+s}} \mathbb{E}_t \sum_{s=0}^{\infty} (\zeta_p)^s \Xi_{t,t+s} \left\{ \begin{aligned} & \left[P_{H,t}^{new} \prod_{l=1}^s (\pi_H)^{(1-\iota_p)} (\pi_{H,t+l-1})^{\iota_p} - MC_{t+s} \right] \times \\ & \left(\frac{P_{H,t}^{new} \prod_{l=1}^s (\pi_H)^{(1-\iota_p)} (\pi_{H,t+l-1})^{\iota_p}}{P_{H,t+s}} \right)^{-\frac{1+\lambda_f}{\lambda_f}} \times \\ & \left\{ \left(\frac{P_{H,t+s}}{P_{CPI,t+s}} \right)^{-\sigma} \left[(1 - (1-n)\omega) M_{t+s} + (1-n)\omega Q_{t+s}^{\sigma} M_{t+s}^F \right] + G_{t+s} \right\} \end{aligned} \right\} \quad (\text{B.51})$$

First order condition can be rearranged as:

$$\mathbb{E}_t \sum_{s=0}^{\infty} (\zeta_p)^s \Xi_{t,t+s} \left\{ \left[\begin{aligned} & -P_{H,t}^{new} P_{H,t+s} \left(\frac{\prod_{l=1}^s (\pi_H)^{(1-lp)} (\pi_{H,t+l-1})^{lp}}{P_{H,t+s}} \right)^{-\frac{1}{\lambda_f}} + \\ & (1 + \lambda_f) MC_{t+s} \left(\frac{\prod_{l=1}^s (\pi_H)^{(1-lp)} (\pi_{H,t+l-1})^{lp}}{P_{H,t+s}} \right)^{-\frac{1+\lambda_f}{\lambda_f}} \end{aligned} \right] \times \left\{ \left(\frac{P_{H,t+s}}{P_{CPI,t+s}} \right)^{-\sigma} \left[\begin{aligned} & (1 - (1-n)\omega) M_{t+s} \\ & + (1-n)\omega Q_{t+s}^{\sigma} M_{t+s}^F \end{aligned} \right] + G_{t+s} \right\} \right\} = 0 \quad (\text{B.52})$$

After some simple algebra the equation above can be written as:

$$\mathbb{E}_t \sum_{s=0}^{\infty} (\zeta_p)^s \Xi_{t,t+s} \left\{ \left[\begin{aligned} & -P_{H,t}^{rel} \frac{P_{H,t+s}}{P_{H,t}} \left(\frac{\prod_{l=1}^s (\pi_H)^{(1-lp)} (\pi_{H,t+l-1})^{lp}}{\frac{P_{H,t+s}}{P_H}} \right)^{-\frac{1}{\lambda_f}} + \\ & (1 + \lambda_f) \bar{MC}_{t+s} \frac{P_{H,t+s}}{P_H} \left(\frac{\prod_{l=1}^s (\pi_A)^{(1-lp)} (\pi_{H,t+l-1})^{lp}}{\frac{P_{H,t+s}}{P_H}} \right)^{-\frac{1+\lambda_f}{\lambda_f}} \end{aligned} \right] \times \left\{ \left(\frac{P_{H,t+s}}{P_{CPI,t+s}} \right)^{-\sigma} \left[\begin{aligned} & (1 - (1-n)\omega) M_{t+s} \\ & + (1-n)\omega Q_{t+s}^{\sigma} M_{t+s}^F \end{aligned} \right] + G_{t+s} \right\} \right\} = 0 \quad (\text{B.53})$$

where $P_{H,t}^{rel} \equiv \frac{P_{H,t}^{new}}{P_{H,t}}$ is the relative price chosen by those firm able to change their price and $\bar{MC}_{t+s} \equiv \frac{MC_{t+s}}{P_{H,t+s}}$ denotes real marginal costs in term of domestically produced goods price.

Note that:

$$\frac{P_{H,t+s}}{P_{H,t}} = \frac{P_{H,t+s}}{P_{H,t+s-1}} \times \frac{P_{H,t+s-1}}{P_{H,t+s-2}} \times \frac{P_{H,t+s-2}}{P_{H,t+s-3}} \times \dots \times \frac{P_{H,t+1}}{P_{H,t}} = \prod_{l=1}^s \pi_{H,t+l} \quad (\text{B.54})$$

Let define

$$X_{t,s} = \frac{\prod_{l=1}^s (\pi_H)^{(1-i_p)} (\pi_{H,t+l-1})^{i_p}}{\prod_{l=1}^s \pi_{H,t+l}} \quad (\text{B.55})$$

Plugging (B.54) into (B.53) and using the definition in (B.55) yields:

$$\mathbb{E}_t \sum_{s=0}^{\infty} (\zeta_p)^s \Xi_{t,t+s} \prod_{l=1}^s \pi_{H,t+l} (X_{t,s})^{-\frac{1+\lambda_f}{\lambda_f}} \times \left\{ \left\{ \left(\frac{P_{H,t+s}}{P_{CPI,t+s}} \right)^{-\sigma} \left[\begin{array}{l} (1 + \lambda_f) \bar{M} C_{t+s} - P_{H,t}^{rel} X_{t,s} \\ (1 - (1-n)\omega) M_{t+s} \\ + (1-n)\omega Q_{t+s}^{\sigma} M_{t+s}^F \end{array} \right] + G_{t+s} \right\} \right\} = 0 \quad (\text{B.56})$$

The price evolution (2.16) in term of relative price can be rewritten as:

$$1 = (1 - \zeta_p) (P_{H,t}^{rel})^{-\frac{1}{\lambda_f}} + \zeta_p \left(\frac{\pi_{H,t-1}^{\iota_p} \pi_H^{(1-\iota_p)}}{\pi_{H,t}} \right)^{-\frac{1}{\lambda_f}} \quad (\text{B.57})$$

Equations (B.56) and (B.57) can be combined to obtain a canonical form of the New-Keynesian Phillips curve.

Firms cost minimization problem yields the following demand for capital and labour inputs:

$$R_t^k = \alpha M C_t \frac{Y_t}{K_t} \quad (\text{B.58})$$

$$W_t = M C_t (1 - \alpha) \frac{Y_t}{N_t} \quad (\text{B.59})$$

Combining equations above yields the production input ratio:

$$\frac{N_t}{K_t} = \frac{1 - \alpha}{\alpha} \frac{R_t^k}{W_t} \quad (\text{B.60})$$

which correspond to equation (2.12) in the main text. The cost of inputs can also be expressed in real term. In this case the previously equation become:

$$\frac{N_t}{K_t} = \frac{1 - \alpha}{\alpha} \frac{\tilde{R}_t^k}{\tilde{W}_t} \quad (\text{B.61})$$

Substitute for Y_t into (B.58) from production function (2.10) and using input ratio (B.60) yields an expression for nominal marginal costs:

$$MC_t = \frac{W_t^{(1-\alpha)} R_t^{K \alpha}}{X_t^{(1-\alpha)} \alpha^\alpha (1 - \alpha)^{(1-\alpha)}} \quad (\text{B.62})$$

which is the expression (2.13) in the text.

Expressing marginal cost in terms of domestic price index gives:

$$\bar{M}C_t = \frac{1}{\alpha^\alpha (1 - \alpha)^{(1-\alpha)}} \frac{\tilde{W}_t^{(1-\alpha)} \tilde{R}_t^{K \alpha}}{X_t^{(1-\alpha)}} \frac{P_{CPI,t}}{P_{H,t}} \quad (\text{B.63})$$

Term of trade

Using the law of one price the term of trade (2.26) can be rewritten as:

$$S_t = \xi_t \frac{P_{F,t}^F}{P_{H,t}} \quad (\text{B.64})$$

B.2.3 The model equilibrium

The equilibrium of the model is made up of the equations (B.42), (B.43), (B.44), (B.45), (B.46), (B.47), (B.48), (B.56), (B.57), (B.61), (B.63), (B.64), (2.10), (2.11), (2.19), (2.27), (2.28), (2.29), (2.30), (2.32), (2.33), (2.34) and the definition of effective capital and CPI inflation. A set of analogous equations for the foreign economy completes the equilibrium definition.

B.2.4 Log-linearization

Let lower-case variables with “ $\hat{\cdot}$ ” denoting variables in log-deviation from steady states and where appropriate expressed in real term. The relevant steady state can be obtained using the same approach described in section A.2.3. Furthermore, under the assumption that country H and country F share the

same preferences, technology and market structure and differs only by their relative size, steady state values are the same for both countries.

The complete set of equations describing the model are:

$$\widehat{\lambda}_t^I = \mathbb{E}_t [\widehat{\lambda}_{t+1}^I] + (\widehat{r}_t - \mathbb{E}_t [\widehat{\pi}_{CPI,t+1}]) \quad (\text{B.65})$$

$$(1 - h\beta)(1 - h)\widehat{\lambda}_t^I = -(1 + h^2\beta)\widehat{c}_t + h\widehat{c}_{t-1} + h\beta\mathbb{E}_t [\widehat{c}_{t+1}] \quad (\text{B.66})$$

$$S''(1)(1 + \beta)\widehat{i}_t = S''(1)\widehat{i}_{t-1} + \beta S''(1)\mathbb{E}_t [\widehat{i}_{t+1}] + (\widehat{\lambda}_t^K - \widehat{\lambda}_t^I) \quad (\text{B.67})$$

$$\widehat{\lambda}_t^K - \widehat{\lambda}_t^I = \beta(1 - \delta)\mathbb{E}_t [\widehat{\lambda}_{t+1}^K - \widehat{\lambda}_{t+1}^I] + (1 - \beta(1 - \delta))\mathbb{E}_t [\widehat{r}_{t+1}^k] - (\widehat{r}_t - \mathbb{E}_t [\widehat{\pi}_{CPI,t+1}]) \quad (\text{B.68})$$

$$R^k \widehat{r}_t^k = a''(u)\widehat{u}_t \quad (\text{B.69})$$

$$\begin{aligned} \widehat{w}_t^{rel} = & \zeta_w \beta \{ \mathbb{E}_t [\widehat{w}_{t+1}] - \widehat{w}_t + \mathbb{E}_t [\widehat{w}_{t+1}^{rel}] - i_w \widehat{\pi}_{CPI,t} + \mathbb{E}_t [\widehat{\pi}_{CPI,t+1}] \} \\ & + \frac{\lambda_w(1 - \zeta_w \beta)}{\lambda_w + (1 + \lambda_w)\varphi} \{ \varphi \widehat{n}_t - \widehat{w}_t - \widehat{\lambda}_t^I \} \end{aligned} \quad (\text{B.70})$$

$$\widehat{w}_t = \widehat{w}_{t-1} - \widehat{\pi}_{CPI,t} + i_w \widehat{\pi}_{CPI,t-1} + \frac{(1 - \zeta_w)}{\zeta_w} \widehat{w}_t^{rel} \quad (\text{B.71})$$

$$\widehat{\pi}_{H,t} = \frac{\beta}{1 + \iota_p \beta} \mathbb{E}_t [\widehat{\pi}_{H,t+1}] + \frac{\iota_p}{1 + \iota_p \beta} \widehat{\pi}_{H,t-1} + \frac{(1 - \zeta_p \beta)(1 - \zeta_p)}{\zeta_p(1 + \iota_p \beta)} m_{Ct} \quad (\text{B.72})$$

$$\widehat{r}_t^k + \widehat{k}_t = \widehat{n}_t + \widehat{w}_t \quad (\text{B.73})$$

$$\widehat{m}_{Ct} = (1 - \alpha)(\widehat{w}_t - \widehat{x}_t) + \alpha \widehat{r}_t^k + (1 - n)\omega \widehat{s}_t \quad (\text{B.74})$$

$$\widehat{s}_t - \widehat{s}_{t-1} = (\widehat{\pi}_{F,t}^F - \widehat{\pi}_{H,t} + \widehat{e}_t - \widehat{e}_{t-1}) \quad (\text{B.75})$$

$$\widehat{y}_t = (1 - \alpha)(\widehat{x}_t + \widehat{n}_t) + \alpha \widehat{k}_t \quad (\text{B.76})$$

$$\widehat{x}_t = \rho_x \widehat{x}_{t-1} + \mu_n \widehat{n}_{t-1} \quad (\text{B.77})$$

$$\widehat{k}_t = (1 - \delta)\widehat{k}_{t-1} + \delta \widehat{i}_t \quad (\text{B.78})$$

$$\widehat{q}_t = (1 - \omega) \widehat{s}_t \quad (\text{B.79})$$

$$\begin{aligned} \widehat{nx}_t &= (1 - n) \omega \left[\frac{C^F}{Y^F} \widehat{c}_t^F + \frac{I^F}{Y^F} \widehat{i}_t^F + a' (u^F) \frac{\overline{K}^F}{Y^F} \widehat{u}_t^F \right] \\ &\quad - (1 - n) \omega \left[\frac{C}{Y} \widehat{c}_t + \frac{I}{Y} \widehat{i}_t + a' (u) \frac{\overline{K}}{Y} \widehat{u}_t \right] \\ &\quad + \left(\frac{C}{Y} + \frac{I}{Y} \right) (1 - n) \omega (\sigma (2 - \omega) - 1) \widehat{s}_t \end{aligned} \quad (\text{B.80})$$

$$\widehat{r}_t = \rho_r \widehat{r}_{t-1} + (1 - \rho_r) \left[\phi_\pi \widehat{\pi}_{CPI,t} + \phi_{gdp} (\widehat{gdp}_t - \widehat{gdp}_{t-1}) \right] \quad (\text{B.81})$$

$$\begin{aligned} \widehat{gdp}_t &= (1 - (1 - n) \omega) \left[\frac{C}{Y} \widehat{c}_t + \frac{I}{Y} \widehat{i}_t \right] \\ &\quad + \sigma (1 - n) \omega \left(\frac{C^F}{Y^F} + \frac{I^F}{Y^F} \right) (2 - \omega) \widehat{s}_t \\ &\quad + (1 - n) \omega \left[\frac{C^F}{Y^F} \widehat{c}_t^F + \frac{I^F}{Y^F} \widehat{i}_t^F \right] \\ &\quad + \frac{G}{Y} \widehat{g}_t \end{aligned} \quad (\text{B.82})$$

$$\widehat{g}_t = \rho_g \widehat{g}_{t-1} + \varepsilon_t^g \quad (\text{B.83})$$

$$\begin{aligned} \widehat{y}_t &= (1 - (1 - n) \omega) \left[\frac{C}{Y} \widehat{c}_t + \frac{I}{Y} \widehat{i}_t + a' (u) \frac{\overline{K}}{Y} \widehat{u}_t \right] \\ &\quad + \sigma (1 - n) \omega \left(\frac{C^F}{Y^F} + \frac{I^F}{Y^F} \right) (2 - \omega) \widehat{s}_t \\ &\quad + (1 - n) \omega \left[\frac{C^F}{Y^F} \widehat{c}_t^F + \frac{I^F}{Y^F} \widehat{i}_t^F + a' (u^F) \frac{\overline{K}^F}{Y^F} \widehat{u}_t^F \right] \\ &\quad + \frac{G}{Y} \widehat{g}_t \end{aligned} \quad (\text{B.84})$$

$$\widehat{q}_t = -\widehat{\lambda}_t + \widehat{\lambda}_t^F \quad (\text{B.85})$$

$$\widehat{\pi}_{CPI,t} = \widehat{\pi}_{H,t} + (1-n)\omega(\widehat{s}_t - \widehat{s}_{t-1}) \quad (\text{B.86})$$

$$\widehat{k}_t = \widehat{u}_t + \widehat{k}_{t-1} \quad (\text{B.87})$$

For the foreign economy the equilibrium conditions equivalent to (B.72), (B.74), (B.82), (B.84), (B.86) are:

$$\widehat{\pi}_{F,t}^F = \frac{\beta}{1 + \iota_p \beta} \mathbb{E}_t [\widehat{\pi}_{F,t+1}^F] + \frac{\iota_p}{1 + \iota_p \beta} \widehat{\pi}_{F,t-1}^F + \frac{(1 - \zeta_p \beta)(1 - \zeta_p)}{\zeta_p(1 + \iota_p \beta)} \widehat{m}c_t^F \quad (\text{B.88})$$

$$\widehat{m}c_t^F = (1 - \alpha)(\widehat{w}_t^F - \widehat{x}_t^F) + \alpha \widehat{r}_t^{k,F} - n\omega \widehat{s}_t \quad (\text{B.89})$$

$$\begin{aligned} \widehat{gdp}_t^F &= (1 - n\omega) \left(\frac{C^F}{Y^F} \widehat{c}_t^F + \frac{I^F}{Y^F} \widehat{i}_t^F \right) + \frac{G^F}{Y^F} g_t^F \\ &\quad - \sigma n\omega \left(\frac{C}{Y} + \frac{I}{Y} \right) (2 - \omega) \widehat{s}_t + n\omega \left(\frac{C}{Y} \widehat{c}_t + \frac{I}{Y} \widehat{i}_t \right) \end{aligned} \quad (\text{B.90})$$

$$\begin{aligned} y_t^F &= (1 - n\omega) \left(\frac{C^F}{Y^F} \widehat{c}_t^F + \frac{I^F}{Y^F} \widehat{i}_t^F + a'(u^F) \frac{\overline{K}^F}{Y^F} u_t^F \right) \\ &\quad - \sigma n\omega \left(\frac{C}{Y} + \frac{I}{Y} \right) (2 - \omega) \widehat{s}_t \\ &\quad + n\omega \left(\frac{C}{Y} \widehat{c}_t + \frac{I}{Y} \widehat{i}_t + a'(u) \frac{\overline{K}}{Y} u_t \right) + \frac{G^F}{Y^F} g_t^F \end{aligned} \quad (\text{B.91})$$

$$\widehat{\pi}_{CPI,t}^F = \widehat{\pi}_{CPI,t}^F - n\omega(\widehat{s}_t - \widehat{s}_{t-1}) \quad (\text{B.92})$$

The equilibrium condition for the foreign economy is completed by a set of equations that, apart from including foreign variables, are identical to equations (B.65), (B.66), (B.67), (B.68), (B.69), (B.70), (B.71), (B.73), (B.76), (B.77), (B.78), (B.81), (B.83) and (B.87).

B.3 Sensitivity analysis

In this section I illustrate the effect of a government spending on consumption and real exchange rate for different degree of openness. Ilzetzi (2013) finds that fiscal multipliers are smaller in open economies than in closed economy. Figure B.1 plots the impulses responses to a government spending shock normalized to 1% of GDP for different levels of the domestic country's size n while keeping all the remaining parameters at their baseline values. In particular I compare the baseline case ($n = 0.20$) with two extreme cases. On one side the closed economy model ($n = 1$) and on the other side the small open economy model ($n = 0$). The figure shows that the response of consumption and GDP is larger for the closed economy respect to the baseline model, which in turn delivers an higher increase in consumption and GDP than the small open economy. These results manly depend on the behaviour of inflation. In fact, the CPI inflation is a weighted average of domestic and imported inflation. It is worth to note that the increase in consumption in the foreign economy (not plotted here) derives from the fall in the level of prices of domestically produced goods. The reduction in domestic inflation, occurring through the LBD mechanism, reduces the CPI inflation for the foreign economy, and by the real interest rate channel, increases foreign consumption. However, since government spending is allocated only to domestically produced goods, the increase in aggregate demand and consequently in hours worked is smaller than the increase in the domestic economy. Thus, for the foreign economy the increase in TFP is smaller and hence there is a lower reduction in the expected path of foreign inflation. This results in a smaller reduction in the CPI inflation for the domestic economy in the baseline case respect to the closed economy alternative. Furthermore, the deterioration of the trade balance implies that a fraction of the increase in domestic consumption involve foreign goods, reducing therefore the increase in the domestic GDP.

In the small open economy version, the domestic economy has no impact on the foreign economy variables. The foreign level of productivity and the level of imported inflation is unchanged. In addition, there is no increase in the demand of domestically produced goods by the foreign economy. Therefore,

the small open economy records a smaller increase in hours worked and in the level of productivity. This results in a weaker decline in the level of real interest rate and a smaller increase in consumption and GDP.

B.4 Incomplete market

The model proposed in the chapter 2 is based on the assumption of complete market and availability of an internationally traded asset. In this section I analyse the effect of departing from this assumption by considering the effects of incomplete markets on the international risk sharing condition. In particular I consider the impact of introducing financial frictions that restrict the set of assets that can be internationally traded.¹

As discussed in Chari et al. (2002) the presence of incomplete market does not suffice *per se* to eliminate the correlation between consumption and RER.

In what follows I present a simple framework to illustrate the main intuition behind this result. I consider the asset market structure proposed in Benigno and Thoenissen (2008). Households in the Home country can trade two nominal risk-less bonds denominated in domestic and foreign currency. To simplify the analysis, households in the Foreign country can trade only in bond issued in their country. Households in the Home country are required to pay a transaction cost for holding foreign bonds. The cost is introduced to eliminate the problem of unit root in foreign bond holding. Considering the simplified economy presented in section 2.5.1 the budget constraint for the Home country household becomes:

$$P_{CPI,t+s}C_{t+s}(i) + B_{t+s}^H(i) + \frac{\xi_{t+s}B_{t+s}^F(j)}{\Theta\left(\frac{\xi_t B_{t+s}^F}{P_{CPI,t+s}}\right)} \leq R_{t+s-1}B_{t+s-1}^H(i)$$

$$R_{t+s-1}^F \xi_{t+s} B_{t+s-1}^F(i) + W_{t+s}(i) N_{t+s}(i) + \Pi_{t+s} - T_{t+s}(i) \quad (\text{B.93})$$

where $B_{t+s}^H(i)$ and $B_{t+s}^F(j)$ denote domestic and foreign bonds hold by agent

¹Another source of imperfect risk sharing has been already discussed in the literature review in the chapter 2 when I comment the households heterogeneity considered in Erceg et al. (2005).

j ; $\Theta(\cdot)$ is a cost function that depends on the net foreign asset position of the Home country economy.

Combining first order conditions for the domestic and the foreign economy and using the definition of the RER yields the following international risk sharing condition:

$$\frac{\mathbb{E}_t U_{c,t+1}}{U_{c,t}} = \frac{\mathbb{E}_t U_{c,t+1}^F}{U_{c,t}^F} \frac{1}{\Theta\left(\frac{\xi_t B_t^F}{P_{CPI,t}}\right)} \frac{Q_t}{\mathbb{E}_t Q_{t+1}} \quad (\text{B.94})$$

The equation above is the equivalent to (2.34) in the main text for the case of incomplete market. Equation (B.94) states an important and well known result: with incomplete markets relative consumption and RER are correlated only in expectation and not period-by-period ex-post as when market are complete. Furthermore, the assumption about financial market structure adds a new element given by the transaction cost function $\Theta(\cdot)$.²

Thus, while with complete markets any change in the relative level of consumption must be compensated by a period-by-period change in the RER, when markets are incomplete, risk sharing is imperfect, hence the RER does not have to change as much as in the case with complete markets. Furthermore, transferring purchasing power from Home to Foreign through the RER channel requires a change in the net foreign assets position of the Home economy.³ Log-linearizing and integrating forward equation (B.94), using the result in (1.26) and an equivalent equation for the foreign economy yields:

$$\hat{q}_t = -\mathbb{E}_t \sum_{s=0}^{\infty} \left[(\hat{r}_{t+s} - \mathbb{E}_t \hat{\pi}_{CPI,t+1+s}) - (\hat{r}_{t+s}^F - \mathbb{E}_t \hat{\pi}_{CPI,t+1+s}^F) + \varepsilon \hat{b}_{t+s} \right] \quad (\text{B.95})$$

²Following Benigno and Thoenissen (2008), the cost function is introduced to eliminate the otherwise arising unit root in foreign bond holdings and solve the model by log-linearization but is not a crucial assumption to examine the correlation between consumption and RER. Chari et al. (2002) do not consider the transaction cost and in the risk sharing condition equivalent to (B.94) the term $\Theta(\cdot)$ disappears.

³It is also possible to show that the change in the net foreign asset position is equal, after considering the transaction cost, to trade balance. The intuition for this result is that an improvement (deterioration) in the trade balance must lead to a corresponding increase (decrease) in the net asset position.

where $\varepsilon = -\Theta'(b)Y$ and $\hat{b}_t = Y^{-1}(\hat{b}_t^F + \hat{e}_t)$ is the net foreign asset position measured in real term and expressed as percent of domestic output.

If the parameter ε is sufficiently small, also with incomplete markets, the RER dynamics is still determined by the relative behaviour of real interest rates as in the case of complete market. Benigno and Thoenissen (2008) set $\varepsilon = 0.001$ in order to generate a 10 basis point spread (per annum) of the domestic interest rate on foreign assets over the foreign rate.

In conclusion, introducing incomplete markets do not have large implications for the model presented in chapter 2.

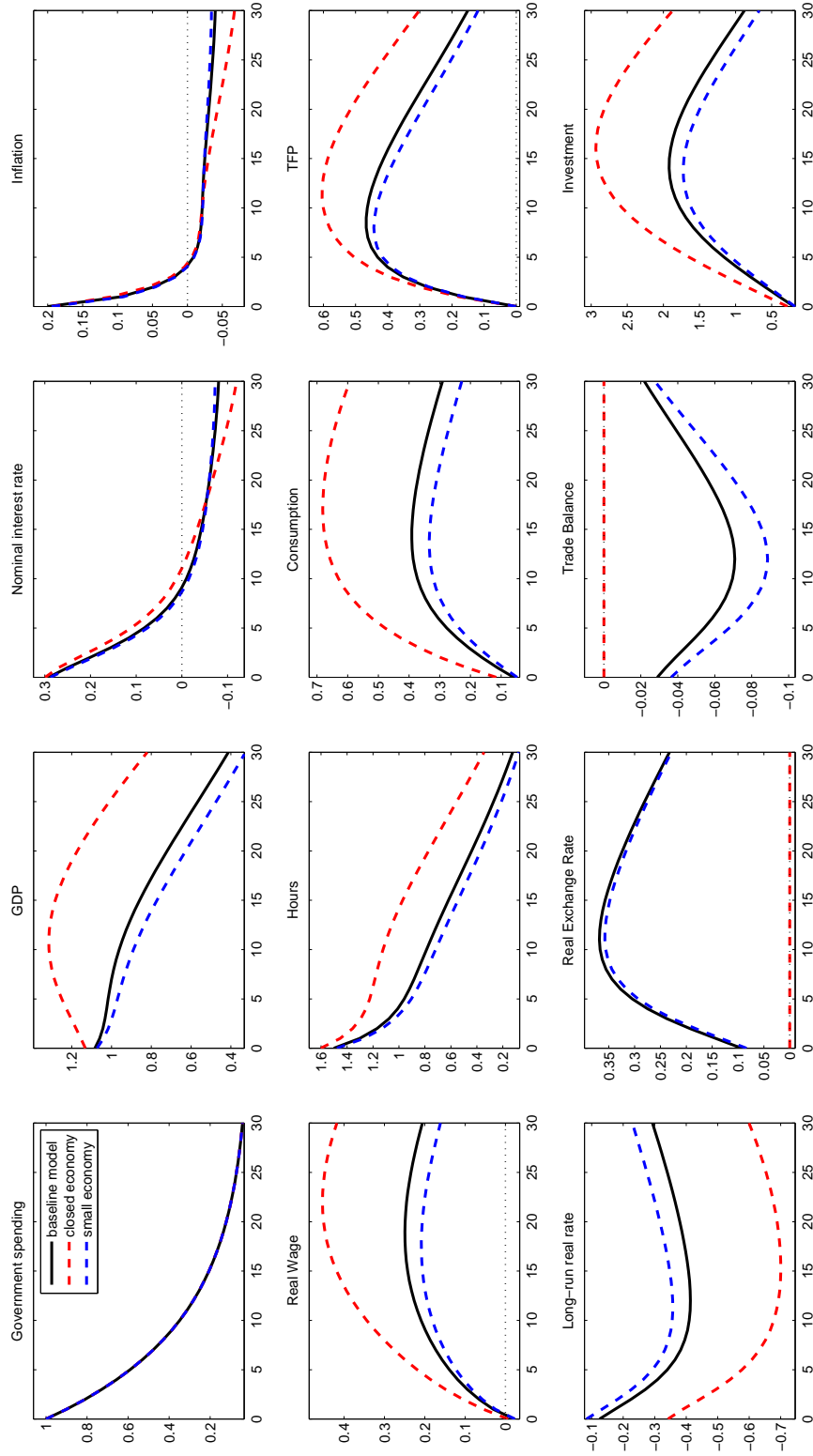


Figure B.1: DSGE responses: sensitivity to domestic economy size. This figure shows impulse responses to a government spending shock equal to 1% of GDP for the full-fledged open economy with LBD for different level of domestic economy's size. Notes: see notes fig. 2.2.

CHAPTER 3

What are the effects of government spending on house prices?

3.1 Introduction

The collapse in the housing market has played a major role in the 2008 crisis (see, for example, Mian and Sufi (2010) and Hall (2011)).

The recent DSGE literature has investigated the effects of fluctuations in residential investments and house prices on business cycles by introducing credit-constrained agents that can use housing wealth (or land) as a collateral. The main motivation that justifies this extension is the growing consensus about the fact that housing wealth could play an important role in accounting for macroeconomics fluctuations.¹

These evidences have forced researchers and policy-makers to explore their potential implications for policy analysis. Most of this literature - reviewed below - has focused on the consequences of the presence of credit constraints on the monetary policy transmission mechanism. By contrast, fiscal policy has received considerable less attention even though, with the nominal interest rate stuck at the zero lower bound in the aftermath of the Great Recession, researchers have reassessed the effectiveness of fiscal policy as a tool to stimulate a troubled economy (Christiano et al. (2011)).

Indeed, the interaction between government spending and house prices

¹See, e.g., Leamer (2007), Iacoviello (2010), Favilukis et al. (2010) and Carroll et al. (2011).

could have relevant implications. To the extent that an increase in government spending boosts house prices, there is an additional propagation mechanism for government expenditure shocks operating through the collateral channel.

Despite its potential relevance, very few papers have examined this mechanism. Afonso and Sousa (2012) provide empirical evidence that a government spending shock yields an increase in consumption and real house prices. Khan and Reza (2014) show that standard DSGE models with housing and collateralized borrowing fail to replicate these stylized facts and only an accommodative monetary policy allows the model to generate a, short lived, increase in house price.

This chapter shows that a modified version of the standard DSGE models with housing and collateralized borrowing is capable of generating a positive response of house prices to a government spending shock. The crucial difference is the assumption that current labour supply affects workers' labour productivity, according to the "learning by doing" (LBD) mechanism proposed in Chang et al. (2002) and discussed in chapter 1. Following Altig, Christiano, Eichenbaum and Lindé (2011), the model is estimated by matching the DSGE impulse responses with the impulse responses of a VAR model estimated using quarterly data for the U.S. over the period 1969:I to 2006:IV. In contrast with the case without LBD, the model generates a persistent increase in house prices in response to a government spending shock, in line with the empirical evidence. The collateral channel amplifies the positive effect on consumption, whereas the impact on the remaining variables is negligible.

The chapter is related to a growing literature highlighting the importance of collateral constraints. Kiyotaki and Moore (1997) is one of the first work to study the interaction between housing wealth and business cycles within the framework of a stochastic general equilibrium model. They show that the presence of credit constraint agents amplifies the effects of technology and income distribution shocks. Davis and Heathcote (2005) develop a model that is able to reproduce the higher volatility of residential investments respect to non residential investments and consumption. Iacoviello (2005) analyses the effect of house prices shocks on consumption when agents faces credit constraints. He shows that if the fraction of credit constraint agents is sufficiently large

an increase in house price can generate an increase in consumption. Iacoviello and Neri (2010) extend the model by introducing the housing production sector. Liu et al. (2011) assume that firms, instead of consumers, are credit constrained and their collateralizable wealth is made up of land and business capital. They find that land price and business investment move together and that they jointly amplify macroeconomic fluctuations. Calza et al. (2013) study the effects of the structure of housing financing on the monetary policy transmission.

The remainder of the chapter is organized as follows. Section 3.2 presents the model; section 3.3 illustrates the key mechanisms determining real house prices and how these are affected by the LBD; section 3.4 describes the VAR identification strategy employed and the approach used to estimate the DSGE model; section 3.5 presents the main results and discuss alternative model specifications; section 3.6 concludes.

3.2 The model

The model is based on Iacoviello and Neri (2010). On the demand side there are two types of households, Patient (or savers) and Impatient (or borrowers), characterized by different discount rates. There is a continuum of measure 1 of agents in each of the two groups. The size of each type of households is measured by its wage share.

Both households consume, work, and accumulate housing. Patient households own physical capital, choose the level of investment and the capital utilization rate, hold government bonds and participate to firms profits. Imperfect contract enforcement implies that the Impatient's borrowing capacity is constrained by the value of the collateral asset, consisting of the housing stock. Because of their high impatience their net worth consists only of their collateral asset.

On the supply side there are two sectors. In the non housing sector a monopolistic competitive firm use labour and capital to produce goods that can be used for both consumption and investment.

In the housing sector a competitive firm combines capital, labour and land to produce new houses.

Following Iacoviello and Neri (2010), I assume prices are sticky in the non-housing sector, whereas in the housing sector prices are flexible. I assume wage frictions in both sectors.

3.2.1 Households

Patient households

Let the P superscript denote variables referring to patient households, the representative patient households maximizes:

$$U(C^P, N^P, H^P) = \mathbb{E}_t \sum_{s=0}^{\infty} (\beta^P)^s \left\{ \begin{aligned} &\ln(C_{t+s}^P - hC_{t-1+s}^P) + j \ln H_{t+s}^P \\ &- \frac{\psi^P}{1+\varphi} \left[(N_{c,t+s}^P)^{1+\varphi} + (N_{h,t+s}^P)^{1+\varphi} \right] \end{aligned} \right\} \quad (3.1)$$

where C_t^P is consumption, H_t^P is the housing stock and $N_{c,t}^P$ and $N_{h,t}^P$ is labour supply respectively in the non-housing and housing sector. I assume that hours in the two sectors are perfect substitutes; φ denotes the inverse of the Frisch elasticity of labour supply; ψ^P is a constant determining the steady state level of labour supply; j is the weight of housing stock into the utility function. β^P is the subjective discount rate of patient households; h denote the degree of habit in consumption.²

The representative patient household maximizes the utility function subject to the flow of fund constraint:

²I assume that the degree of habit in consumption, the weight of housing stock into the utility function and the Frisch elasticity of labour supply are the same for the two groups of households.

$$\begin{aligned}
& C_t^P + I_{c,t} + I_{h,t} + q_t [H_t^P - (1 - \delta_h) H_{t-1}^P] - B_t^P + D_t \\
& + p_{l,t} L_t \leq -\frac{R_{t-1} B_{t-1}^P}{\pi_t} + \frac{R_{t-1} D_{t-1}}{\pi_t} + \frac{W_{c,t}^P}{P_t} N_{c,t}^P \\
& + \frac{W_{h,t}^P}{P_t} N_{h,t}^P + \left[\frac{R_{c,t}^k}{P_t} u_{c,t} - a(u_{c,t}) \right] \bar{K}_{c,t-1} \\
& + \left[\frac{R_{h,t}^k}{P_t} u_{h,t} - a(u_{h,t}) \right] \bar{K}_{h,t-1} + \left(p_{l,t} + \frac{R_{l,t}}{P_t} \right) L_{t-1} - T_t^P + F_t \quad (3.2)
\end{aligned}$$

Patient households choose consumption C_t^P , investment in physical capital in the non-housing sector $I_{c,t}$ and in the housing sector $I_{h,t}$; q_t is relative price of houses (expressed in term of consumption units); households decide the current amount of the housing stock H_t^P given the level of the undepreciated housing stock from the previous period $(1 - \delta_h) H_{t-1}^P$, where δ_h denotes the depreciation rate of the housing stock. Loans to impatient households B_t^P pay one unit of consumption goods in any state of nature in period $t + 1$. Thus, the risk-less yield on one unit of loan is determined by the nominal interest rate R_t and inflation $\pi_t = \frac{P_t}{P_{t-1}}$; D_t is the amount of government debt held by patient households. I assume that the real gross return on government debt is the same as the return on loans to impatient households; L_t denotes land and $p_{l,t}$ and $R_{l,t}$ are its relative price and its nominal rental rate. I assume that total land is fixed and is owned only by patient households. $W_{c,t}^P$ and $W_{h,t}^P$ are nominal wages earned by the representative patient household in the two production sectors. Patient households rent capital $u_{c,t} \bar{K}_{c,t-1}$ and $u_{h,t} \bar{K}_{h,t-1}$ to firms. Similarly to Smets and Wouters (2003), given the chosen level of capital utilization $u_{c,t}$ and $u_{h,t}$, patient households receive the nominal rental rates of capital $R_{c,t}^k$ and $R_{h,t}^k$ and pay the adjustment utilization cost $a(u_{c,t})$ and $a(u_{h,t})$ expressed in term of consumption goods. The cost function $a(\bullet)$ is an increasing function and has the property that in steady state $u_c = u_h = 1$, $a(1) = 0$ and $a''(1) > 0$; F_t are dividends from intermediate firms paid to patient households. T_t^P is a non distortionary tax levied on patient agents.³

³Since by assumption only patient agents hold government bond, capital and land, make

Following Christiano et al. (2005), the capital accumulation process for the non-housing and housing sector is described by:

$$\bar{K}_{c,t} = (1 - \delta_{kc}) \bar{K}_{c,t-1} + \left[1 - S \left(\frac{I_{c,t}}{I_{c,t-1}} \right) \right] I_{c,t} \quad (3.3)$$

$$\bar{K}_{h,t} = (1 - \delta_{kh}) \bar{K}_{h,t-1} + \left[1 - S \left(\frac{I_{h,t}}{I_{h,t-1}} \right) \right] I_{h,t} \quad (3.4)$$

where $S(\cdot)$ denotes the investment adjustment costs, with $S(1) = S(1)' = 0$ and $S(1)'' > 0$. δ_{kc} and δ_{kh} are the depreciation rates of capital in each sector.

Impatient households

Let the "I" superscript denote variables referring to impatient households. Assuming that impatient households have the same utility function as patient households, the representative impatient agent maximizes:

$$U(C^I, N^I, H^I) = \mathbb{E}_t \sum_{s=0}^{\infty} (\beta^I)^s \left\{ \ln(C_{t+s}^I - hC_{t-1+s}^I) + j \ln H_{t+s}^I - \frac{\psi^I}{1+\varphi} \left[(N_{c,t+s}^I)^{1+\varphi} + (N_{h,t+s}^I)^{1+\varphi} \right] \right\} \quad (3.5)$$

where β^I is the subjective discount factor of patient households, and by assumption $\beta^I < \beta^P$.

Following Iacoviello and Neri (2010), Impatient households do not own neither physical capital nor land. Furthermore I assume that they do not participate to firms profits and do not hold government debt. Hence their budget constraint is:

$$\begin{aligned} C_t^I - B_t^I + q_t [H_t^I - (1 - \delta_h) H_{t-1}^I] &= -\frac{R_{t-1} B_{t-1}^I}{\pi_t} \\ &+ \frac{W_{c,t}^I}{P_t} N_{c,t}^I + \frac{W_{h,t}^I}{P_t} N_{h,t}^I - T_t^I \end{aligned} \quad (3.6)$$

investment decisions and receive profits from firms, I drop the "P" superscript for these variables.

Impatient households also faces the credit constraint:

$$B_t^I \leq m \mathbb{E}_t \left(\frac{q_{t+1} H_t^I \pi_{t+1}}{R_t} \right) \quad (3.7)$$

where m is the loan-to-value (LTV) ratio. Thus, the amount impatient households can borrow is limited by the fraction m of housing wealth $q_t H_t^I$ which serves as a collateral asset.

3.2.2 Labour contractors and wage setting

Within the two groups, Patient and Impatient, each agent supply heterogeneous labour services $i \in (0, 1)$ to a labour contractor. Each household acts as a monopolistic suppliers of labour service of type i . There are four different categories of labour services grouped by sector and households: $N_{c,t}^P(i)$, $N_{h,t}^P(i)$, $N_{c,t}^I(i)$ and $N_{h,t}^I(i)$. There is one contractor for each type of labour service. Labour contractors are perfect competitive firms. They aggregate the differentiated labour services into an homogeneous labour service hired by producers in the housing and non housing sectors. For each production sector $l = \{c, h\}$ and for each type of households $d = \{P, I\}$ the aggregation function is defined by:

$$N_{l,t}^d = \left[\int_0^1 N_{l,t}^d(i)^{\frac{1}{1+\lambda_w}} di \right]^{1+\lambda_w} \quad (3.8)$$

where $\lambda_w > 0$ governs the degree of substitution between the different labour services and determines the wage mark-up over the marginal rate of substitution between labour and consumption. I assume that the wage mark-up is the same across households and sectors.

Labour contractors choose differentiated labour service inputs to maximize profits. The first order condition for profit maximization yields the following labour demand for i -type labour service:

$$N_{l,t}^d(i) = \left(\frac{W_{l,t}^d(i)}{W_{l,t}^d} \right)^{-\frac{1+\lambda_w}{\lambda_w}} N_{l,t}^d \quad (3.9)$$

Households face Calvo-style wage setting frictions. In each period the fraction $\zeta_{l,w}$ of households are unable to readjust their wage. In this case households set their wage according to:

$$W_{l,t}^d(i) = (\pi_{t-1})^{\iota_{w,l}} (\pi)^{1-\iota_{w,l}} W_{l,t-1}^d(i) \quad (3.10)$$

where variables without time subscript denote steady state levels. I assume that within each sector Patient and Impatient share the same probability of changing wages. Those households able to re-optimize their wage solve:

$$\max_{W_{l,t}^{d,new}} \mathbb{E}_t \sum_{s=0}^{\infty} (\zeta_{l,w} \beta^d)^s \left\{ -\psi^d \frac{(N_{l,t+s}^d(i))^{1+\varphi}}{1+\varphi} \right\} \quad (3.11)$$

subject to the relevant budget constraint, to labour demand (3.9) and to wage indexation scheme:

$$W_{l,t+s}^d(i) = \prod_{g=1}^s (\pi)^{(1-i_{w,l})} (\pi_{t+g-1})^{i_{w,l}} W_{l,t}^{d,new}(i) \quad (3.12)$$

Considering a symmetric equilibrium in which all households able to set a new wage chose the same level, the following law of motion for wages can be derived:

$$W_{l,t}^d = \left\{ (1 - \zeta_{l,w}) \left(W_{l,t}^{d,new} \right)^{-\frac{1}{\lambda_w}} + \zeta_{l,w} \left[(\pi)^{(1-i_{w,l})} (\pi_{t-1})^{i_{w,l}} W_{l,t-1}^d \right]^{-\frac{1}{\lambda_w}} \right\}^{-\lambda_w} \quad (3.13)$$

3.2.3 Firms

Non-housing sector

The final good producer in the non housing sector is a perfect competitive firm that aggregates a continuum of intermediate goods $Y(j)$ to obtain the final good Y_t using the following aggregation technology:

$$Y_t = \left[\int_0^1 Y_t(j)^{\frac{1}{1+\lambda_f}} dj \right]^{1+\lambda_f} \quad (3.14)$$

where λ_f is a fixed parameter which depends on the degree of substitution between the different intermediate goods and regulates the price mark-up. Let $P_t(j)$ be the price of the intermediate good j , profit maximization leads to the following first-order condition:

$$Y_t(j) = \left(\frac{P_t(j)}{P_t} \right)^{-\frac{1+\lambda_f}{\lambda_f}} Y_t \quad (3.15)$$

Combing equation above with the zero profit condition yields the following definition of the aggregate price level:

$$P_t = \left[\int_0^1 P_t(j)^{-\frac{1}{\lambda_f}} dj \right]^{-\lambda_f} \quad (3.16)$$

The monopolistic intermediate firm $j \in (0, 1)$ in the non-housing sector produces the good j according to the following production function:

$$Y_t(j) = A_t \left((X_{c,t}^P N_{c,t}^P(j))^\gamma (X_{c,t}^I N_{c,t}^I(j))^{(1-\gamma)} \right)^{1-\alpha_c} K_{c,t}^{\alpha_c}(j) \quad (3.17)$$

where α_c denotes the capital share; γ measures the relative size of patient households in term of labour income share; $K_{c,t} = u_{c,t} \bar{K}_{c,t-1}$ is the effective capital; A_t is a productivity shock that affects the non housing sector and evolves according to:

$$\ln A_t = (1 - \rho_a) \ln A + \rho_a \ln A_{t-1} + \varepsilon_t^a \quad (3.18)$$

where $\varepsilon_t^a \sim (0, \sigma_a^2)$.

Following Chang et al. (2002), $X_{c,t}^P$ and $X_{c,t}^I$ are the skills level of labour suppliers in the non housing sector. The stock of knowledge depends on hours worked in the past and evolves according to :

$$X_{c,t}^P = (X_{c,t-1}^P)^{\rho_x} (N_{c,t-1}^P)^{\mu_n} \quad (3.19)$$

$$X_{c,t}^I = (X_{c,t-1}^I)^{\rho_x} (N_{c,t-1}^I)^{\mu_n} \quad (3.20)$$

where $0 < \rho_x < 1$ and $\mu_n \geq 0$.

Nominal wages $W_{c,t}^P$ and $W_{c,t}^I$ and the rental rate of capital $R_{c,t}^K$ are given for intermediate goods producers. Let MC_t denoting nominal marginal costs, the following demand for labour and capital inputs can be derived from cost minimization:

$$W_{c,t}^P = \gamma (1 - \alpha_c) MC_t \frac{Y_t(j)}{N_{c,t}^P(j)} \quad (3.21)$$

$$W_{c,t}^I = (1 - \gamma) (1 - \alpha_c) MC_t \frac{Y_t(j)}{N_{c,t}^I(j)} \quad (3.22)$$

$$R_{c,t}^k = \alpha_c MC_t \frac{Y_t(j)}{K_{c,t}(j)} \quad (3.23)$$

Following Calvo (1983) I assume that in every period a fraction of firm ζ_p cannot re-optimize their prices $P_t(j)$. In this case firms adjust their prices mechanically according to the rule:

$$P_t(j) = (\pi_{t-1})^{\iota_p} (\pi)^{1-\iota_p} \quad (3.24)$$

The fraction $(1 - \zeta_p)$ of firms able to re-optimize their price chose the new price to solve:

$$\max_{P_t(j)^{new}} \mathbb{E}_t \left[\sum_{s=0}^{\infty} (\zeta_p \beta^P)^s \Xi_{t+s}^P Y_{t+s}(j) \times \left(P(j)^{new} \left(\prod_{g=1}^s (\pi_{t-1+g})^{\iota_p} (\pi)^{1-\iota_p} \right) - MC_{t+s} \right) \right] \quad (3.25)$$

subject to demand of the j -type good:

$$Y_{t+s}(j) = \left[\frac{P(j)^{new} \left(\prod_{g=1}^s (\pi_{t-1+g})^{\iota_p} (\pi)^{1-\iota_p} \right)}{P_{t+s}} \right]^{-\frac{1+\lambda_f}{\lambda_f}} Y_{t+s} \quad (3.26)$$

where, given the assumption that only one group of households gets profit from owning firms, the term $(\beta^P)^s \Xi_{t+s}^p$ is the today value of a future dollar for patient households.

Finally, considering only a symmetric equilibrium where all firms choose the same price, the law of motion for the aggregate price level is:

$$P_t = \left[(1 - \zeta_p) (P_t^{new})^{-\frac{1}{\lambda_f}} + \zeta_p ((\pi_{t-1})^{\iota_p} (\pi)^{1-\iota_p} P_{t-1})^{-\frac{1}{\lambda_f}} \right]^{\lambda_f} \quad (3.27)$$

Housing production sector

New houses are produced by a perfect competitive firm combining labour, capital and land. The representative firm in the housing sector faces the following production technology:

$$IH_t = \left[(X_{h,t}^P N_{h,t}^P)^\gamma (X_{h,t}^I N_{h,t}^I)^{(1-\gamma)} \right]^{(1-\alpha_h-\alpha_l)} K_{h,t}^{\alpha_h} L_t^{\alpha_l} \quad (3.28)$$

where α_h and α_l denote capital and land shares; $K_{h,t} = u_{h,t} \bar{K}_{h,t-1}$ is the effective capital in the housing sector; $X_{h,t}^P$ and $X_{h,t}^I$ is the stock of knowledge of patient and impatient households in the housing sector and evolves according to:

$$X_{h,t}^P = (X_{h,t-1}^P)^{\rho_x} (N_{h,t-1}^P)^{\mu_n} \quad (3.29)$$

$$X_{h,t}^I = (X_{h,t-1}^I)^{\rho_x} (N_{h,t-1}^I)^{\mu_n} \quad (3.30)$$

Recalling that by assumption prices in this sector are flexible the profit maximization problem yields the following demand for inputs (after land is

normalized to one):

$$\frac{W_{h,t}^P}{P_t} = \gamma (1 - \alpha_h - \alpha_l) q_t \frac{IH_t}{N_{h,t}^P} \quad (3.31)$$

$$\frac{W_{h,t}^I}{P_t} = (1 - \gamma) (1 - \alpha_h - \alpha_l) q_t \frac{IH_t}{N_{h,t}^I} \quad (3.32)$$

$$\frac{R_{h,t}^k}{P_t} = \alpha_h q_t \frac{IH_t}{K_{h,t}} \quad (3.33)$$

$$\frac{R_t^l}{P_t} = \alpha_l q_t IH_t \quad (3.34)$$

3.2.4 Government policies

As in Iacoviello and Neri (2010), the central bank sets the nominal interest rate R_t according to a Taylor rule that responds to inflation and GDP growth:

$$\frac{R_t}{R} = \left(\frac{R_{t-1}}{R} \right)^{\rho_r} \left[\left(\frac{\pi_t}{\pi} \right)^{\phi_\pi} \left(\left(\frac{GDP_t}{GDP_{t-1}} \right)^{\phi_{gdp}} \right) \right]^{(1-\rho_r)} \exp(\varepsilon_t^r) \quad (3.35)$$

where variables without time subscript denote steady state values; ε_t^r is an independently and identically distributed monetary shock with standard deviation σ_r ; GDP_t is defined as:

$$GDP_t = C_t^P + C_t^I + I_{c,t} + I_{h,t} + qIH_t + G_t \quad (3.36)$$

Government spending evolves according to the following exogenous process:

$$\log G_t = (1 - \rho_g) \log G + \rho_g \log G_{t-1} + \varepsilon_t^g \quad (3.37)$$

with $\varepsilon_t^g \sim (0, \sigma_g^2)$.

The government budget constraint is of the form:

$$G_t + \frac{R_t D_{t-1}}{\Pi_t} = D_t + T_t \quad (3.38)$$

where D_t and T_t are respectively total government debt and lump-sum taxes

aggregated across all households.

Finally, following Leeper, Plante and Traum (2010) fiscal policy rule, expressed in log-linearized form, is:

$$\widehat{t}_t = \Psi_{gdp} \widehat{gdp}_t + \Psi_d \widehat{d}_{t-1} \quad (3.39)$$

where lower case letters with '^' denote variables expressed in deviation from steady states. Ψ_{gdp} captures the automatic stabilizer component of taxes and Ψ_d is the parameter regulating the speed of debt stabilization.

3.2.5 Market clearing and aggregate variables

Assuming that government spending is allocated only to non-housing sector, market clearing condition in the non-housing sector is:

$$Y_t = C_t^P + C_t^I + I_{c,t} + I_{h,t} + a(u_{c,t}) \bar{K}_{c,t-1} + a(u_{h,t}) \bar{K}_{h,t-1} + G_t \quad (3.40)$$

Whereas, the housing sector equilibrium is:

$$IH_t = H_t^P + H_t^I - (1 - \delta_h) (H_{t-1}^P + H_{t-1}^I) \quad (3.41)$$

Let variables without superscript denote aggregate levels, consumption and investment are given by:

$$C_t = C_t^P + C_t^I \quad (3.42)$$

$$I_t = I_{c,t} + I_{h,t} \quad (3.43)$$

The aggregate level of wages and hours worked in the two sectors are:

$$W_{h,t} = W_{h,t}^P + W_{h,t}^I \quad (3.44)$$

$$W_{c,t} = W_{c,t}^P + W_{c,t}^I \quad (3.45)$$

$$N_{h,t} = \gamma N_{h,t}^P + (1 - \gamma) N_{h,t}^I \quad (3.46)$$

$$N_{c,t} = \gamma N_{c,t}^P + (1 - \gamma) N_{c,t}^I \quad (3.47)$$

Whereas, the aggregate level of wages and hours worked in all sectors are:

$$W_t = W_{h,t} + W_{c,t} \quad (3.48)$$

$$N_t = N_{h,t} + N_{c,t} \quad (3.49)$$

Finally, assuming that each household pays the same per capita amount of taxes yields:

$$T_t^P = \gamma T_t \quad T_t^I = (1 - \gamma) T_t \quad (3.50)$$

3.3 The LBD mechanism and the collateral channel

Before turning to model estimation, in this section I illustrate the mechanisms through which introducing LBD can bring the response of real house prices to a government spending shock closer in line with the data. In what follows, ‘ $\hat{\cdot}$ ’ denotes variables expressed in log-deviation from steady state. In order to simplify the analysis I assume in this section no habit in consumption ($h = 0$).

Let denote with $\hat{\lambda}_t^B$ the Lagrangian multiplier associated to the borrowing constraint in (3.7), the Euler equation for impatient household is:

$$\hat{c}_t^I = \frac{\beta^I}{\beta^P} \mathbb{E}_t \hat{c}_{t+1}^I - \frac{\beta^I}{\beta^P} (\hat{r}_t - \mathbb{E}_t [\hat{\pi}_{t+1}]) - \left(1 - \frac{\beta^I}{\beta^P}\right) \hat{\lambda}_t^B \quad (3.51)$$

The last term on the RHS reflects the collateral effect and measures the consequence of the level of borrowing on the current level of consumption.

Integrating forward equations (3.51) yields:

$$\widehat{c}_t^I = -\frac{\beta^I}{\beta^P} \mathbb{E}_t \sum_{s=0}^{\infty} \left(\frac{\beta^I}{\beta^P} \right)^s (\widehat{r}_{t+s} - \widehat{\pi}_{t+s+1}) - \left(1 - \frac{\beta^I}{\beta^P} \right) \sum_{s=0}^{\infty} \left(\frac{\beta^I}{\beta^P} \right)^s \mathbb{E}_t [\widehat{\lambda}_{t+s}^B] \quad (3.52)$$

Equation (3.52) shows the mechanism through which the collateral channel affects consumption. As for patient households, the level of consumption for impatient households depends on the sum of period by period real interest rate, as well as the amount they can borrow, as indicated by the second term on the RHS in the equation above. Given the inverse relationship between the level of borrowing and its shadow value represented by $\widehat{\lambda}_t^B$, an increase in the level of borrowing leads to a reduction in its shadow value and hence an increase in consumption. The borrowing constrain (3.7) immediately reveals that the amount impatient household can borrow is a function of the expected level of house prices.

To understand the effect of including LBD on the relative house prices consider that housing demand for patient households can be written as:

$$\widehat{q}_t = (1 - \beta^P (1 - \delta_h)) (\widehat{c}_t^P - \widehat{h}_t^P) + \beta (1 - \delta_h) \mathbb{E}_t [\widehat{q}_{t+1} - (\widehat{r}_t - \widehat{\pi}_{t+1})] \quad (3.53)$$

Equation above states that the cost of purchasing one unit of housing expressed in term of consumption good (i.e. the relative price of housing) must be equal to its marginal benefit. The latter value is made up of two elements. First, the effect of housing on the households utility, measured by the marginal rate of substitution between consumption and housing (first term on the RHS). Second, housing can be used as an asset to smooth consumption over time, as alternative to lending. The second term on the RHS states that the desired level of housing stock for the patient households depends on the difference between the discounted resale value of the undepreciated housing stock and the return on loans to impatient households (or to government).

Similarly, the demand for housing by impatient households is given by:

$$\begin{aligned}\hat{q}_t = & [1 - \beta^I (1 - \delta_h) - m (\beta^P - \beta^I)] (\hat{c}_t^I - \hat{h}_t^I) \\ & + [\beta^I (1 - \delta_h) + m (\beta^P - \beta^I)] \mathbb{E}_t [\hat{q}_{t+1} - (\hat{r}_t - \hat{\pi}_{t+1})] \\ & + (\beta^P - \beta^I) [m - (1 - \delta_h)] (\hat{\lambda}_t^B + \hat{c}_t^I)\end{aligned}\quad (3.54)$$

Relative to equation (3.53), the demand for housing by impatient households has an additional term which express the value of housing as collateral asset for borrowing expressed in term of consumption good.

By integrating forward equation (3.53) yields:

$$\begin{aligned}\hat{q}_t = & (1 - \beta^P (1 - \delta_h)) \mathbb{E}_t \sum_{s=0}^{\infty} (\beta^P (1 - \delta_h))^s (\hat{c}_{t+s}^P - \hat{h}_{t+s}^P) \\ & - \beta^P (1 - \delta_h) \mathbb{E}_t \sum_{s=0}^{\infty} (\beta^P (1 - \delta_h))^s (\hat{r}_{t+s} - \hat{\pi}_{t+1+s})\end{aligned}\quad (3.55)$$

Whereas by integrating equation (3.54) gives

$$\begin{aligned}\hat{q}_t = & [1 - \beta^I (1 - \delta_h) - m (\beta^P - \beta^I)] \mathbb{E}_t \sum_{s=0}^{\infty} \Xi^s (\hat{c}_{t+s}^I - \hat{h}_{t+s}^I) \\ & - [\beta^I (1 - \delta_h) + m (\beta^P - \beta^I)] \mathbb{E}_t \sum_{s=0}^{\infty} \Xi^s (\hat{r}_{t+s} - \hat{\pi}_{t+1+s}) \\ & + (\beta^P - \beta^I) \{m - (1 - \delta_h)\} \mathbb{E}_t \sum_{s=0}^{\infty} \Xi^s (\hat{\lambda}_{t+s}^B + \hat{c}_{t+s}^I)\end{aligned}\quad (3.56)$$

where $\Xi \equiv [\beta^I (1 - \delta_h) + m (\beta^P - \beta^I)]$

Thus, the relative house price depends on the sum of marginal rate of substitution between consumption and housing, and (negatively) on the sum of real interest rate and the value of housing as collateral for impatient households. Therefore, the same mechanism highlighted in the first chapter, by reducing the real interest rate, increases the relative price of housing. In addition, the LBD mechanism has an indirect impact on the relative price of house through two additional channels. First, by equation (3.52) the decrease

of the real interest rate increases consumption and, through the effect on the marginal rate of substitution between consumption and housing, strengthens the positive effect on the relative price of houses.

Second, the increase in house price incentives impatient households to increase their level of housing in order to increment the amount they can borrow. The increased demand for housing further increases house prices. This last effect is absent if there is no collateral channel.

3.4 Econometric methodology

The model is estimated using the econometric methodology described in the chapter 1.

The structural VAR model is of the form:

$$AZ_t = c + \sum_{j=1}^p B_j Z_{t-j} + \varepsilon_t \quad (3.57)$$

where Z_t is a vector of observable variables, p is the lag length and ε_t is a vector of structural shocks. A and B_j are matrix of coefficients. My VAR model has 10 variables, which appear in this order: government spending, GDP per hours, inflation, real houses price, GDP, government debt, private consumption, wages, residential investment and nominal interest rate. Where appropriate, variables are expressed in logs of real per capital terms. More details about data are provided in the appendix to this chapter. Three shocks are considered: a government spending, a monetary policy and a productivity shock. The identification strategy follows the approach used in chapter 1. The VAR includes four lags, a constant and a linear time trend. The sample runs from 1966:1 to 2006:4. The beginning of the sample is dictated by data availability, in particularly with regard to the data on government debt, while the end date falls before the 2008 recession.

The estimated parameters are chosen to minimize the distance between the VAR-based impulse response functions of variables in the VAR to the three shocks considered and the corresponding DSGE response functions in

order to minimize the objective function in 1.38. The impact responses of the DSGE model are restricted to account for the restrictions imposed by the VAR estimation strategy.

I estimate the baseline model and two alternative models in which in turn either LBD or the collateral channel is switched off (respectively setting $\mu_n = \rho_x = 0$ and $\gamma = 1$).

3.5 Results

In this section I briefly discuss the model parameterization before turning to the simulation.

3.5.1 Parameters set a priori

Table 3.1 reports the value of the parameters set outside the model.

For the households preference parameters I choose conventional values and I set the inverse of the elasticity of labour supply φ equal to 3, a standard value used in the literature. For the discount factors I use the values adopted in Iacoviello and Neri (2010): the patient households discount factor β^P is equal to 0.9925 and corresponds to a steady state nominal interest rate around 3% per year; the impatient households discount factor β^I is equal to 0.97.

The housing stock depreciation rate δ_h is set to 0.008 a value in line with Iacoviello and Neri (2010). The weights on housing in the utility function j is set equal to 0.18. These values imply a residential investment to GDP ratio equal to 4.7% and a value of housing wealth respect to GDP equal to 1.46. The depreciation rates on capital δ_{kc} and δ_{kh} are set to 0.025 in both sectors. The capital share α_c and α_h are both set to 0.30. Land share α_l is assumed to be 0.10 as in Iacoviello and Neri (2010). I fix λ_w and λ_f equal to 0.05 implying wage and price mark-ups equal to 5%. The implied business investment to GDP ratio is about 21%. The LTV ratio m is set to 0.75, a value in line with the average LTV ratio over the period considered.⁴ The government spending to GDP ratio corresponds to its sample average of 0.20.

⁴For a discussion on this point see Iacoviello and Neri (2010).

Finally, I set the wage indexation coefficient for the housing sector to $\iota_{w,h} = 0$, and the capital utilization adjustment cost to $u'' = 0.01$ because when I tried to estimate these parameters my algorithm pushed those estimates close to zero. Furthermore, I also opted to fix the response of monetary policy to inflation and the investment adjustment cost. I chose to fix these parameters because my estimation algorithm drove those parameters toward implausible large values. Therefore I set $\phi_\pi = 1.50$, which is a quite standard value employed in the literature and $S''(1) = 5.74$ as in Smets and Wouters (2007).

3.5.2 Estimated parameters

The value of the estimates and the corresponding standard errors for the baseline model are listed in the first column of tables 3.2 and 3.3. All estimates are statistically significant and are consistent with previous studies. The fraction of patient households γ is equal to 0.72. The value is in line with the evidences reported in the previous literature.⁵

The parameters regulating the LBD mechanism μ_n and ρ_x are respectively equal to 0.45 and 0.57. My estimate implies an higher initial impact and a faster return to the steady state level respect to the estimates reported in Chang et al. (2002).

The degree of wage stickiness for the non housing sector $\zeta_{c,w}$ is larger than the corresponding value for the housing sector $\zeta_{h,w}$ and are respectively equal to 0.60 and 0.46. These values implies that the average wage duration is 2.5 quarters in the non housing sector and 1.8 quarters in the housing sector. The degree of stickiness in prices ζ_p is equal to 0.63 corresponding to an average price duration of 2.7 quarters. These parameters are within the range of values found in previous studies.⁶ The level of habit in consumption h is 0.61. The estimates of the monetary and fiscal policy rules are in line with previous

⁵Jappelli (1990) using the 1983 Survey of Consumer Finances found the fraction of unconstrained household to be equal to 0.80; Iacoviello (2005), using an estimation strategy similar to the approach employed in this paper estimates a fraction of patient households equal to 0.65. In Iacoviello and Neri (2010) the parameter is equal to 0.79.

⁶See section 2.4

evidence, as well as the shocks auto-regression coefficients.

Regarding the two alternative specifications, the model without collateral channel delivers estimates very similar to the values found for the baseline model.

Instead, for the model without LBD the estimates diverges from the values reported for the baseline model. The most notable differences are the degree of price stickiness, much larger for the model without LBD, and the share of patient households near to one. This value implies that the weight of credit constrained agents in the economy is extremely small. The model virtually collapses to the case where there is no collateral channel. Thus, it is difficult to isolate the effects deriving from switching off the LBD channel from the effects derived as a result that the collateral channel is almost absent.

Table 3.4 reports steady state properties of the model evaluated at the estimated parameters for the baseline model.

3.5.3 Impulse responses

I now consider the capacity of the DSGE model presented in section 3.2 to replicate the VAR estimates of the dynamic response of the economy to the three shocks considered.

Figures 3.1-3.3 compare the baseline DSGE (solid line) with the VAR-based responses (dashed line). Light grey area denotes VAR 95% confidence interval. I consider a log-linearized approximation of the model around a deterministic steady state in which inflation is zero. The responses of interest rates and inflation are measured as annualized percentage points deviation from the corresponding steady state level. The remaining variables are expressed in quarterly percentage deviation from their own steady state levels. Time on the x-axis is measured in quarters.

Overall, the model is pretty successful at reproducing the VAR responses and in general delivers impulses response within the VAR confidence intervals.

Figure 3.1 displays the response to a government spending shock equal to one standard deviation innovation. The model is able to capture the main features revealed in the data: the persistent increase in consumption, house

prices and output to hours ratio. However, specially for the real house prices, the response generated by the model is sensibly smaller than the corresponding VAR point estimate.

Figure 3.2 shows the response to an around 50 basis point monetary policy shock. It is worth highlighting that the model is able to capture the "price puzzle" phenomenon, according to which in response to a contractionary monetary policy shock inflation initially increases. In fact, in a model featuring LBD, an increase in the nominal interest rate reduces the output to hours ratio, which leads to an increase in marginal costs and in turn to an initial increase in inflation.

Finally, figure 3.3 reports the response to a natural technology shock. Also in this case the model responses are in general close to the VAR generated responses and within the confidence intervals.

In order to disentangle the different propagation mechanisms included in my model, figures 3.4-3.6 plot the responses to one unit standard innovation to the three shocks considered. I report the impulse responses for the baseline model and for the two alternative specifications, together with the VAR-based responses and confidence intervals.

The LBD mechanism appears to be a crucial feature in order to match VAR based impulse response functions.

Figure 3.4 illustrates that the LBD mechanism is crucial to generate a response of consumption and house prices to a government spending shock of the same sign as the VAR model. Absent this channel, the response of consumption and house prices to a government spending shock would be negative rather than positive and the level of productivity, measured by the output per hour ratio, would be unaffected. As a result, without LBD the model also fails to mimic the decline in inflation and interest rate.

Figure 3.5 shows that LBD is also decisive to capture the initial increase in inflation in response to a positive monetary policy shock. Furthermore, the model with LBD delivers amplified responses for several variables making it more successful at reproducing the VAR responses.

Finally, figure 3.6 suggests that, absent LBD, variables are in general quite unresponsive to technology shocks. However, such unresponsiveness is more

likely produced by the large degree of price stickiness rather than the absence of skills accumulation.

By contrast, the collateral channel has a minor role. For the government spending shock the collateral channel is quantitatively, but not qualitatively, important to generate a response of consumption in line with the data. Without the collateral channel the response of consumption to a government spending shock is still positive but significantly smaller than in the baseline case. In fact, the increase in house prices raises the collateral capacity of constrained households, and yields a larger increase in aggregate consumption. For the remaining variables the responses are similar and the collateral channel does not appear to play a significant role. Similarly, the collateral channel amplifies the fall of consumption in response to a positive monetary policy shock respect to the case when the collateral channel is switched off. Finally, the responses to a technology shock remain virtually unaffected when the collateral channel is switched off.

3.5.4 The main sources of fluctuation

Figure 3.7 displays the forecast error variance decomposition of GDP, consumption, real house price, inflation and nominal interest rate at various horizons. Because of the restrictions imposed on the DSGE based impulse responses to account for the restrictions required by the VAR identification strategy, on impact the monetary shock has effect only on the nominal interest rate.

Government spending account for much of the movement in GDP while monetary and technology shocks plays only a minor role.

On impact movements of consumption are mainly driven by technology shocks. In the following periods government spending and monetary shocks provide a larger contribution.

On impact real house price is quite unresponsive to government spending shocks and its variation is mostly explained by technology shocks. After one year, government spending and monetary shocks explains respectively about 25% and 12% of house price total variance. In the long-run the government spending shock account for about two-thirds of the total variance of house

prices.

Inflation is mainly driven by technology shocks and only in the long-run government spending shocks contribute significantly to changes in inflation. By contrast the monetary policy has a very limited role and in the long-run account for about 1.5% of total variance of inflation.⁷

Finally, much of the change in nominal interest rate is explained on impact by monetary shocks, whereas in the following periods the technology shock is the main driving force, probably because of the relative contribution of technology shock in explaining variation in the inflation rate.

3.6 Conclusion

This chapter investigate the effects of government spending shocks on real house prices. The main result of the present chapter is to show that including a Learning-By-Doing mechanism in a standard new Keynesian DSGE model with housing production and collateralized borrowing enables the model to reproduce the increase in real house prices observed in the data. This result mainly derives from the reduction in the long-term real interest rate generated by the LBD as discussed in chapter 1. I show that in my model collateral effects can bring a larger increase in consumption in response to a government spending shock, whereas the effect on the other variables considered is negligible.

⁷In Smets and Wouters (2007) monetary policy shocks in the long-run explain less than 5% of the total variance of inflation.

Table 3.1: Fixed parameters

Parameter	Description	Value
φ	inverse of labour supply elasticity	3
β^P	patient discount factor	0.9925
β^I	impatient discount factor	0.97
δ_h	housing depreciation rate	0.008
j	weight of housing into the utility function	0.18
δ_{kh}, δ_{kc}	capital depreciation rate	0.025
α_c, α_h	capital share	0.30
α_l	land share	0.10
λ_w	steady state wage mark-up	0.05
λ_f	steady state price mark-up	0.05
m	loan-to-value (LTV)	0.75
$\frac{G}{GDP}$	government spending to GDP ratio	0.20
$\iota_{w,h}$	wage indexation to past inflation: housing sector	0
u''	capital utilization cost	0.01
ϕ_π	monetary rule: response to inflation	1.50
S''	investment adjustment cost	5.74

Table 3.2: Estimated parameters and standard errors: shocks process

Parameter		Model		
		Baseline	Without LBD	Without collateral channel
σ_r	monetary shock: standard deviation	0.16 (0.012)	0.13 (0.016)	0.16 (0.013)
σ_a	productivity shock: standard deviation	0.46 (0.026)	0.47 (0.025)	0.45 (0.026)
σ_g	government shock: standard deviation	0.66 (0.030)	0.70 (0.032)	0.65 (0.030)
ρ_g	government spending: autocorrelation	0.96 (0.008)	0.92 (0.011)	0.96 (0.008)
ρ_a	productivity shock: autocorrelation	0.63 (0.046)	0.65 (0.037)	0.60 (0.046)

Table 3.3: Estimated parameters and standard errors: structural parameters

Parameter		Model		
		Baseline	Without LBD	Without collateral channel
ρ_r	monetary rule: interest smoothing	0.72 (0.013)	0.88 (0.013)	0.73 (0.012)
ϕ_{gdp}	monetary rule: GDP growth	0.47 (0.045)	0.83 (0.114)	0.50 (0.046)
$\zeta_{c,w}$	probability of wage fixed: non housing sector	0.60 (0.017)	0.58 (0.026)	0.58 (0.019)
$\zeta_{h,w}$	probability of wage fixed: housing sector	0.46 (0.025)	0.85 (0.039)	0.44 (0.025)
$\iota_{w,c}$	wage indexation: non-housing sector	0.58 (0.065)	0.99 (0.718)	0.58 (0.057)
ι_p	price indexation to past inflation	0.40 (0.141)	0.99 (0.055)	0.37 (0.136)
ζ_p	probability of price fixed	0.63 (0.026)	0.96 (0.004)	0.60 (0.026)
h	consumption habit	0.61 (0.045)	0.72 (0.040)	0.47 (0.047)
μ_n	Learning-By-Doing (response to past hours)	0.45 (0.041)	-	0.50 (0.043)
ρ_x	Learning-By-Doing (autocorrelation)	0.57 (0.042)	-	0.54 (0.043)
Ψ_d	fiscal policy rule: government debt	0.26 (0.028)	0.32 (0.038)	0.24 (0.028)
Ψ_{gdp}	fiscal policy rule: GDP	0.69 (0.064)	0.43 (0.073)	0.67 (0.061)
γ	share of patient households	0.72 (0.061)	0.99 (0.052)	-

Table 3.4: Steady-state ratios

Parameter	Description	Value
$4 \times R - 1$	annualized nominal interest rate	3%
C/GDP	consumption share	54 %
I/GDP	non-residential investment share	21%
qIH/GDP	residential investment share	4.7 %
$K_c/(4 \times GDP)$	capital to GDP ratio: non-housing sector	2.09
$K_h/(4 \times GDP)$	capital to GDP ratio: housing sector	0.04
$qH/(4 \times GDP)$	housing wealth	1.46

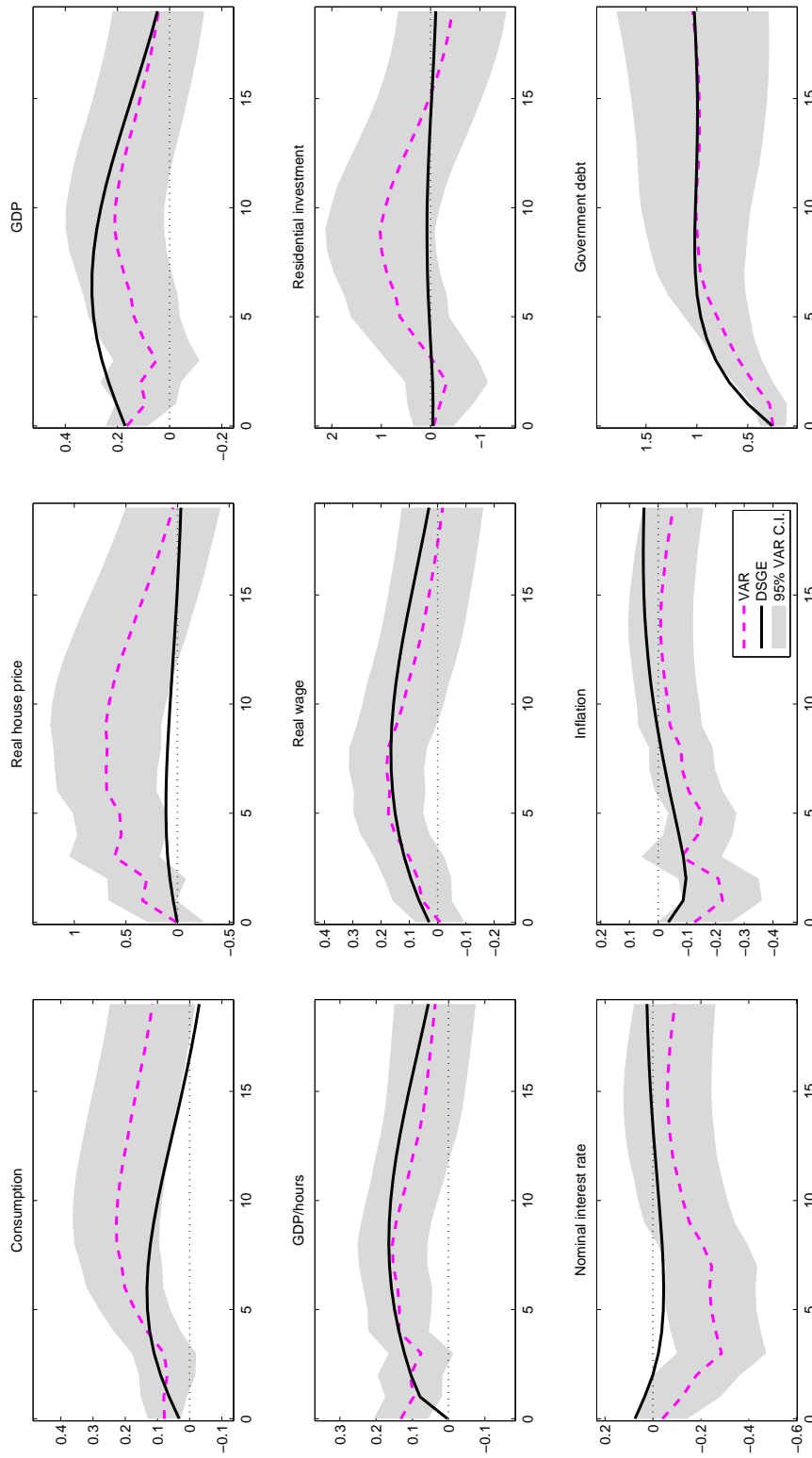


Figure 3.1: Responses to a government spending shock: VAR and baseline DSGE. This figure shows impulse responses to a positive government spending shock.

Notes: Responses are expressed in percentage deviation from steady state (or pre-shock period for the VAR) with the exception of the nominal interest rate and inflation which are measured as annualized percentage points deviation from steady state. Time on the *x-axis* is measured in quarters. The shock is equal to one standard deviation innovation.

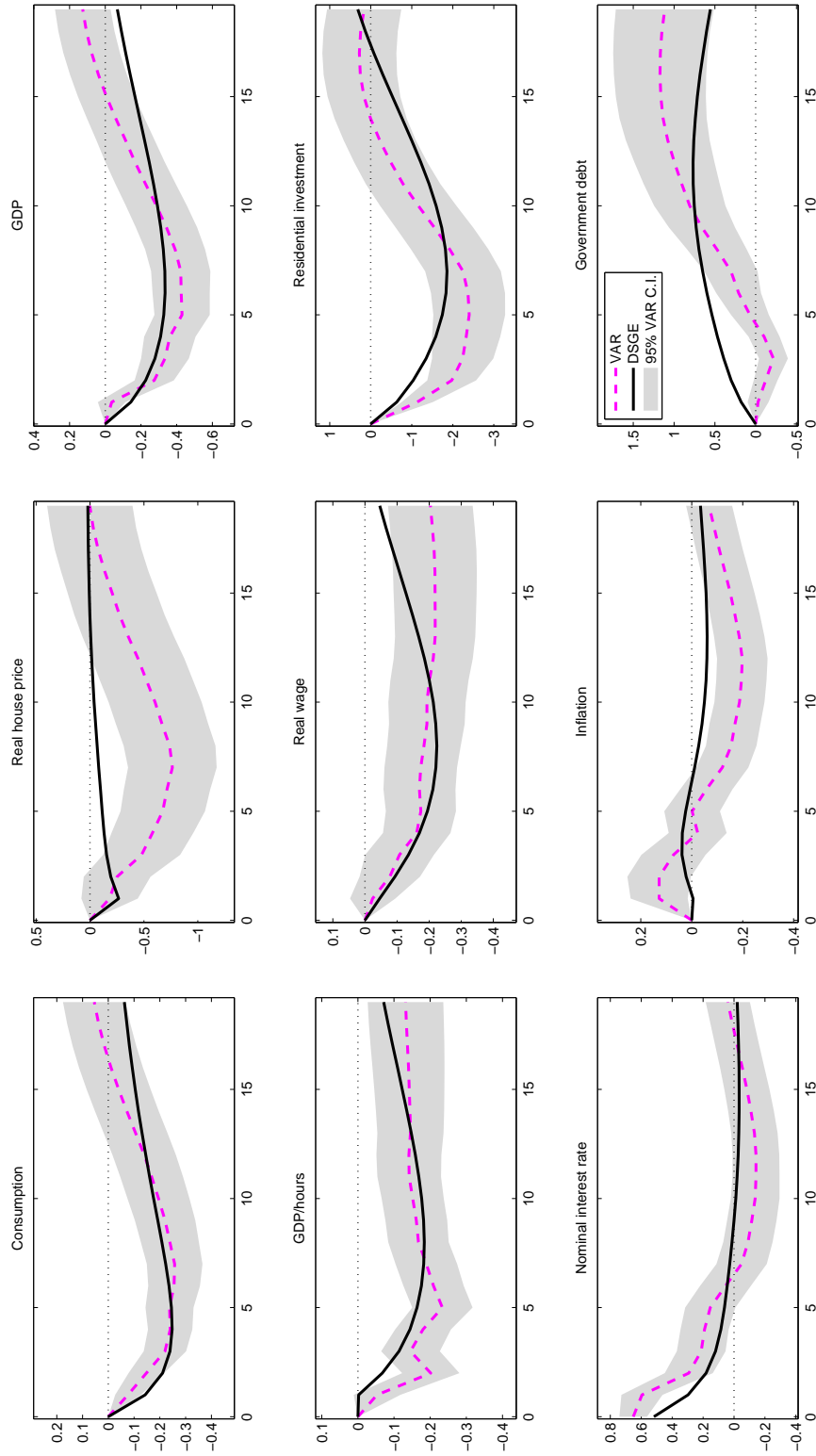


Figure 3.2: Responses to a monetary policy shock: VAR and baseline DSGE. This figure shows impulse responses to a positive monetary shock. Notes: see fig. 3.1.

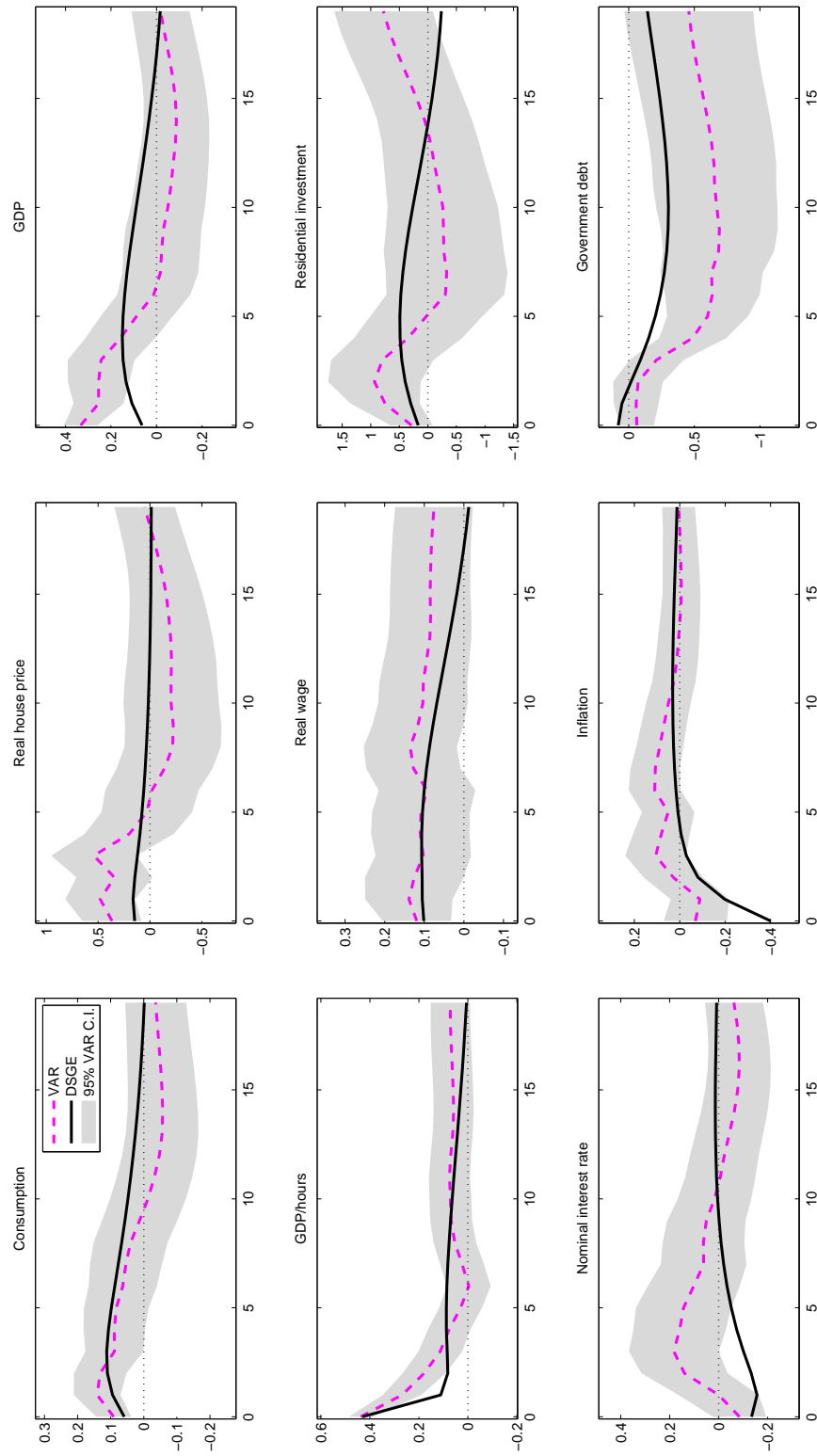


Figure 3.3: Responses to a productivity shock: VAR and baseline DSGE. This figure shows impulse responses to a positive productivity shock. Notes: see fig. 3.1.

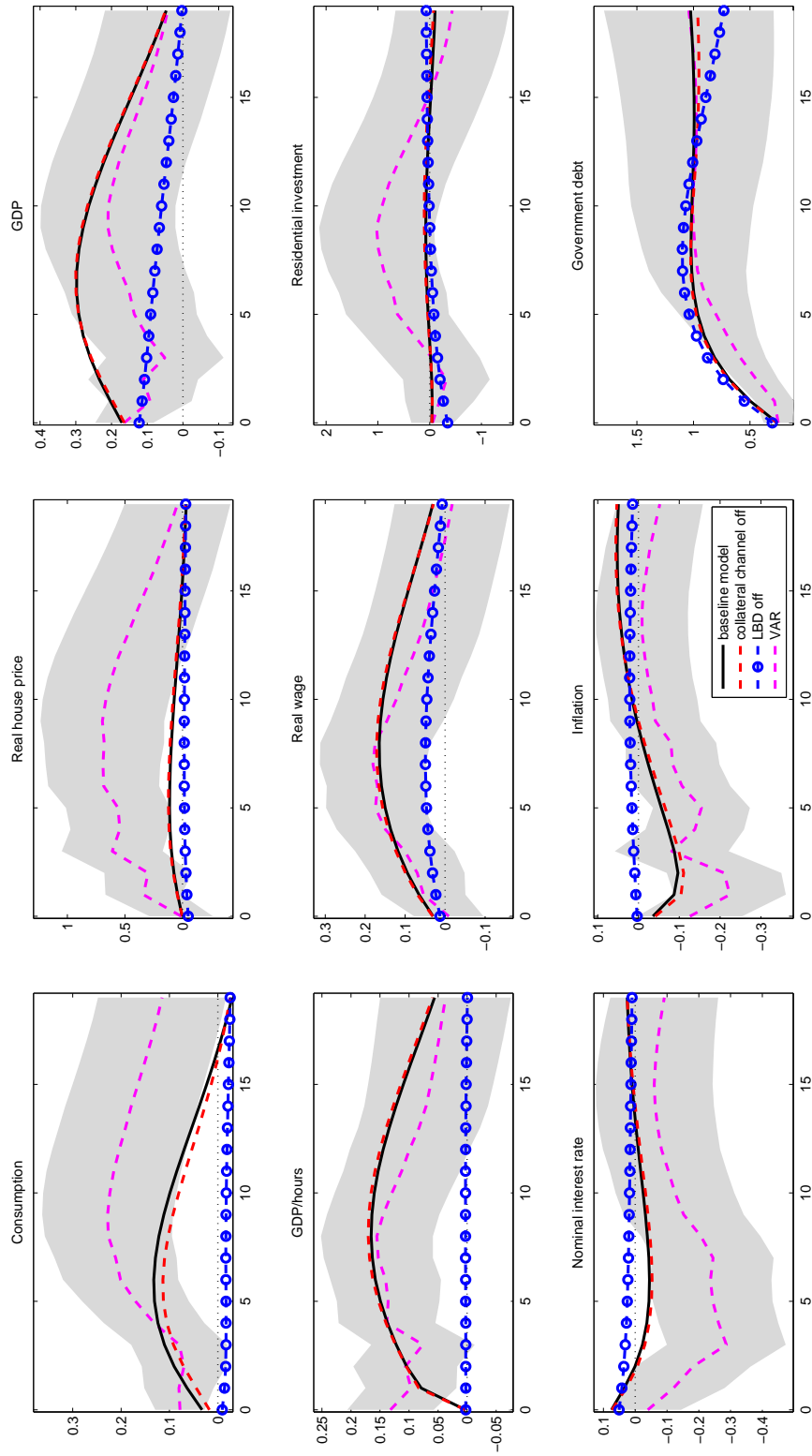


Figure 3.4: Responses to a government spending shock: baseline DSGE and alternative specifications. This figure shows impulse responses to a government spending shock for different DSGE specifications and VAR model. Notes: see fig. 3.1.

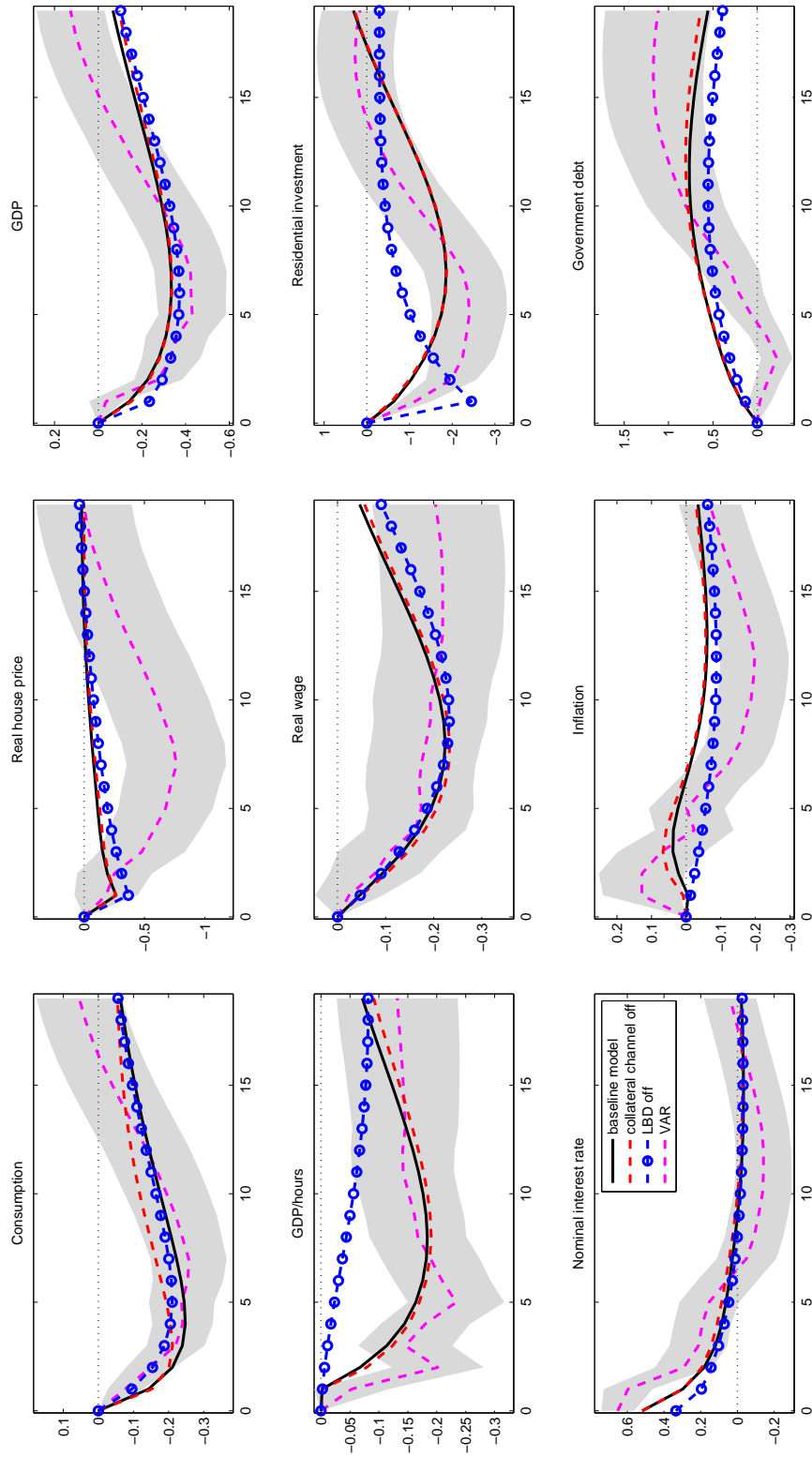


Figure 3.5: Responses to a monetary policy shock: baseline DSGE and alternative specifications. This figure shows impulse responses to an increase in nominal interest rate for different DSGE specifications and VAR model. Notes: see fig. 3.1

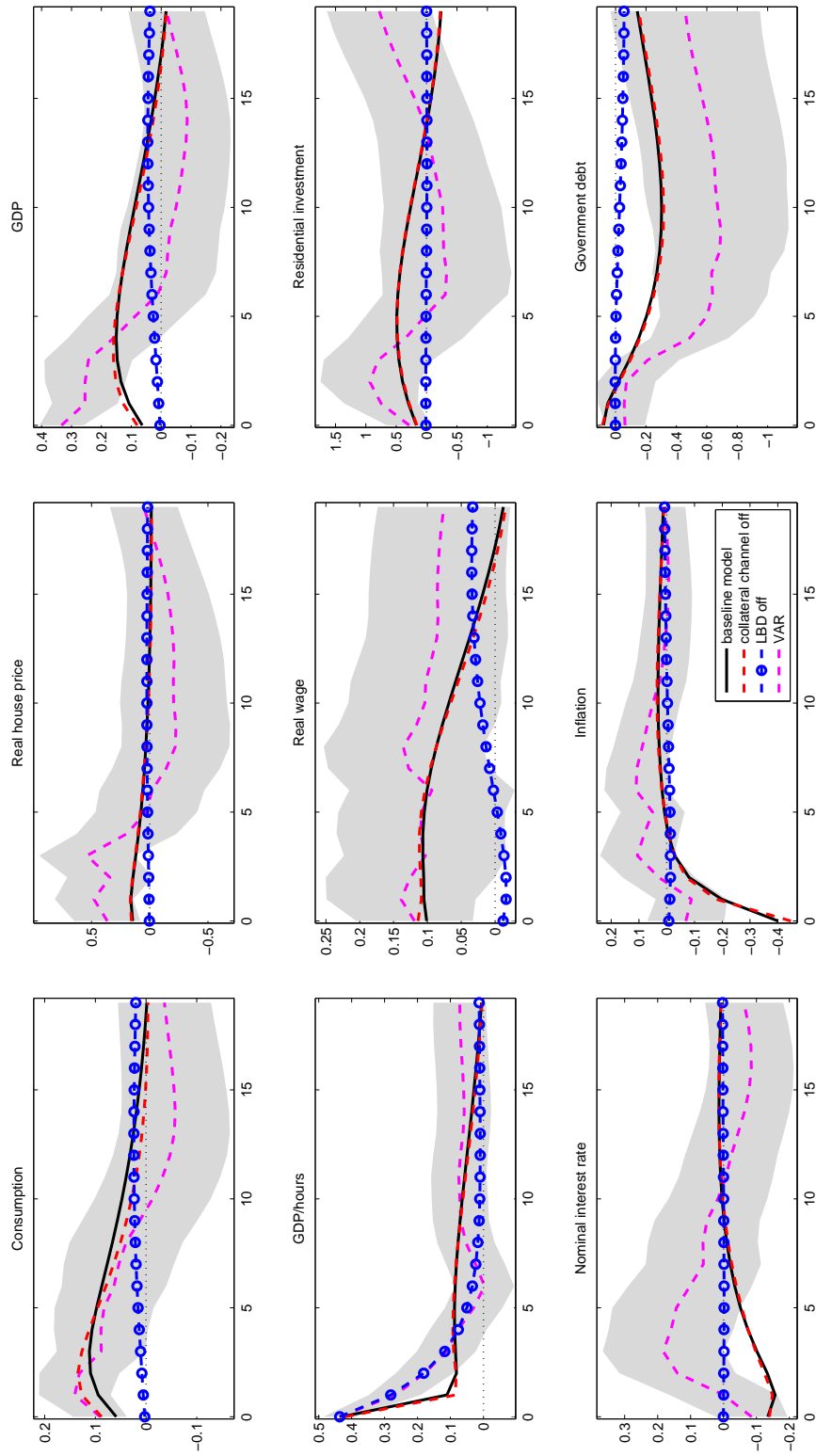


Figure 3.6: Responses to a productivity shock: baseline DSGE and alternative specifications. This figure shows impulse responses to a positive productivity shock for different DSGE specifications and VAR model. Notes: see fig. 3.1

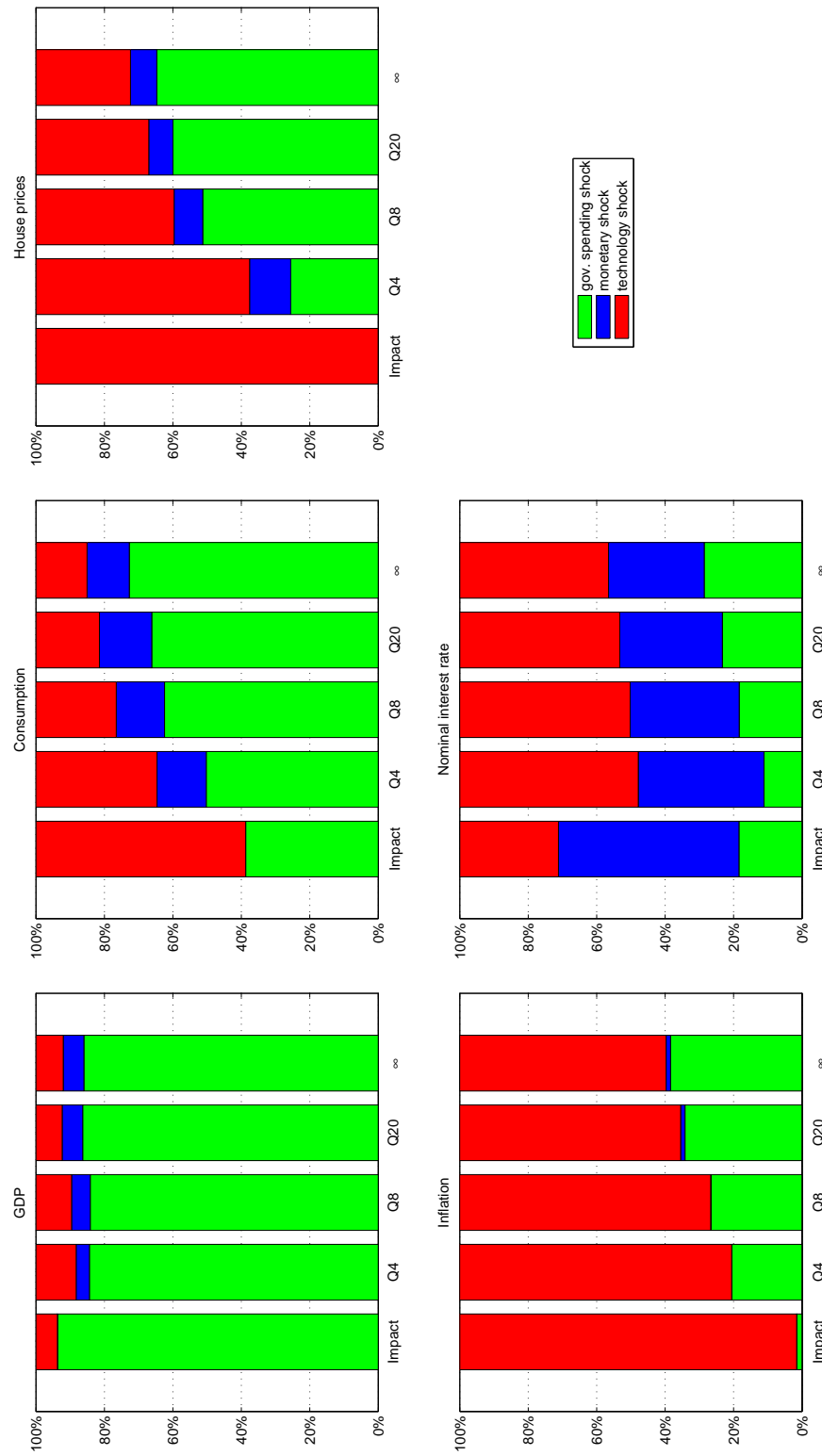


Figure 3.7: Forecast error variance decomposition. This figure shows the forecast error variance decomposition over different horizons.

APPENDIX C

Appendix to chapter 3

C.1 Data

This section describes more in details data employed in the estimation of the VAR model presented in section 3.4.

Residential investment: Residential investment. Table 1.1.5 line 12. Source: Bureau of Economic Analysis (BEA); Note: Seasonally adjusted at annual rates.

Real House prices: Median Sales Price for New Houses Sold in the United States (MSPNHSUS). Source: FRED, Federal Reserve Bank of ST. Louise. Prices are converted in real term using the GDP price index.

The description of the remaining variables and the relevant transformations are reported in the appendix to chapter 1.

C.2 Model derivation

In this section I define the set of equations describing the model, I briefly discuss how to derive the relevant steady states, and I provide the complete set of log-linearized equations. In what follow the symbol “ \sim ” denotes variables expressed in real term.

C.2.1 First order conditions

Households

Let $\lambda_t^{I,P}$ denote the marginal utility of consumption for Patient households and $\lambda_t^{K_h}$ denote the value of installed capital. First order conditions for patient households with respect to consumption C_t^P , lending B_t^P (or equivalently bond holding D_t), housing H_t^P , investment $I_{h,t}$ and $I_{c,t}$, capital $\bar{K}_{h,t}$ and $\bar{K}_{c,t}$ and capital utilization $u_{h,t}$ and $u_{c,t}$ in both sectors are:

$$\lambda_t^{I,P} = \left[\frac{1}{(C_t^P - hC_{t-1}^P)} - \frac{\beta^P h}{(\mathbb{E}_t [C_{t+1}^P] - hC_t^P)} \right] \quad (C.1)$$

$$\lambda_t^{I,P} = \beta^P \mathbb{E}_t \left[\lambda_{t+1}^{I,P} \frac{R_t}{\pi_{t+1}} \right] \quad (C.2)$$

$$\lambda_t^{I,P} q_t = \frac{j}{H_t^P} + \beta^P (1 - \delta_h) \mathbb{E}_t [\lambda_{t+1}^{I,P} q_{t+1}] \quad (C.3)$$

$$\begin{aligned} \lambda_t^{I,P} &= \lambda_t^{K_h} \left\{ 1 - S_h \left(\frac{I_{h,t}}{I_{h,t-1}} \right) - S'_h \left(\frac{I_{h,t}}{I_{h,t-1}} \right) \frac{I_{h,t}}{I_{h,t-1}} \right\} \\ &\quad + \beta^P \mathbb{E}_t \left[\lambda_{t+1}^{K_h} S'_h \left(\frac{I_{h,t+1}}{I_{h,t}} \right) \left(\frac{I_{h,t+1}}{I_{h,t}} \right)^2 \right] \end{aligned} \quad (C.4)$$

$$\begin{aligned} \lambda_t^{I,P} &= \lambda_t^{K_c} \left\{ 1 - S_c \left(\frac{I_{c,t}}{I_{c,t-1}} \right) - S'_c \left(\frac{I_{c,t}}{I_{c,t-1}} \right) \frac{I_{c,t}}{I_{c,t-1}} \right\} \\ &\quad + \beta^P \mathbb{E}_t \left[\lambda_{t+1}^{K_c} S'_c \left(\frac{I_{c,t+1}}{I_{c,t}} \right) \left(\frac{I_{c,t+1}}{I_{c,t}} \right)^2 \right] \end{aligned} \quad (C.5)$$

$$\lambda_t^{K_h} = \beta^P \mathbb{E}_t \lambda_{t+1}^{I,P} \left[\tilde{R}_{h,t+1}^k u_{h,t+1} - a_h(u_{h,t+1}) \right] + \beta^P (1 - \delta_{kh}) \mathbb{E}_t [\lambda_{t+1}^{K_h}] \quad (C.6)$$

$$\lambda_t^{K_c} = \beta^P \mathbb{E}_t \lambda_{t+1}^{I,P} \left[\tilde{R}_{c,t+1}^k u_{c,t+1} - a_c(u_{c,t+1}) \right] + \beta^P (1 - \delta_{kc}) \mathbb{E}_t [\lambda_{t+1}^{K_c}] \quad (C.7)$$

$$\tilde{R}_{h,t}^k = a'(u_{h,t}) \quad (\text{C.8})$$

$$\tilde{R}_{c,t}^k = a'(u_{c,t}) \quad (\text{C.9})$$

Similarly, for impatient households first order conditions with respect to consumption C_t^I , borrowing B_t^I and housing H_t^I are:

$$\lambda_t^{I,I} = \left[\frac{1}{(C_t^I - h^I C_{t-1}^I)} - \frac{\beta^I h^I}{(\mathbb{E}_t [C_{t+1}^I] - h C_t^I)} \right] \quad (\text{C.10})$$

$$\lambda_t^{I,I} = \lambda_t^B + \beta^I \mathbb{E}_t \left[\lambda_{t+1}^{I,I} \frac{R_t}{\pi_{t+1}} \right] \quad (\text{C.11})$$

$$\lambda_t^{I,I} q_t = \frac{j}{H_t^I} + \beta^I (1 - \delta_h) \mathbb{E}_t \left(\lambda_{t+1}^{I,I} q_{t+1} \right) + \lambda_t^B m \mathbb{E}_t \left(q_{t+1} \frac{\pi_{t+1}}{R_t} \right) \quad (\text{C.12})$$

where λ_t^B is the Lagrangian multiplier associated to the borrowing constraint (3.7).

The part of the model describing the representative impatient households is completed by the budget constraint (3.6) and the borrowing constraint (3.7). Expressing variables in real term and under the assumption that in equilibrium the latter constraint holds with equality yields:

$$C_t^I - B_t^I + q_t [H_t^I - (1 - \delta_h) H_{t-1}^I] + T_t^I = -\frac{R_{t-1}}{\pi_t} B_{t-1}^I + \tilde{W}_{c,t}^I N_{c,t}^I + \tilde{W}_{h,t}^I N_{h,t}^I \quad (\text{C.13})$$

$$B_t^I = m \mathbb{E}_t \left(q_{t+1} H_t^I \frac{\pi_{t+1}}{R_t} \right) \quad (\text{C.14})$$

Wage setting

For each production sector $l = \{c, h\}$ and for each type of households $d = \{P, I\}$, the first order condition for the wage setting problem defined in equation (3.11), after some straightforward algebra, can be written as:

$$\mathbb{E}_t \sum_{s=0}^{\infty} (\zeta_{l,w} \beta^d)^s \left[\left(X_{t,s}^W W_{l,t}^{d,rel} \frac{\tilde{W}_{l,t}^d}{\tilde{W}_{l,t+s}^d} \right)^{-\frac{1+\lambda_w}{\lambda_w}} N_{l,t+s}^d \right] \lambda_{t+s}^{I,d} \times$$

$$\left\{ (1 + \lambda_w) \left(X_{t,s}^W W_{l,t}^{d,rel} \frac{\tilde{W}_{l,t}^d}{\tilde{W}_{l,t+s}^d} \right)^{-\frac{(1+\lambda_w)\varphi}{\lambda_w}} \psi^d \frac{(N_{l,t+s}^d)^{\varphi}}{\lambda_{t+s}^{I,d}} - X_{t,s}^W W_{l,t}^{d,rel} \tilde{W}_{l,t}^d \right\} = 0 \quad (C.15)$$

where $X_{t,s}^W \equiv \frac{\prod_{g=1}^s (\pi)^{(1-i_{w,l})} (\pi_{t+g-1})^{i_{w,l}}}{\prod_{g=1}^s \pi_{t+g}}$ and $W_{l,t}^{d,rel} \equiv \frac{W_t^{d,new}}{W_{l,t}^d}$ is the relative wage

chosen by those households that are allowed to re-optimize their wage respect to the level of wages at time t . Wage evolution (3.13) expressed in term of relative wage is:

$$\left(\tilde{W}_{l,t}^d \right)^{-\frac{1}{\lambda_w}} = (1 - \zeta_w) \left(W_{l,t}^{d,rel} \tilde{W}_{l,t}^d \right)^{-\frac{1}{\lambda_w}} + \zeta_{l,w} \left[\frac{(\pi)^{(1-i_{w,l})} (\pi_{t-1})^{i_{w,l}}}{\pi_t} \tilde{W}_{l,t-1}^d \right]^{-\frac{1}{\lambda_w}} \quad (C.16)$$

Firms

The input demand from the non-housing sector firms (3.21)-(3.23) can be written in real term as:

$$\tilde{W}_{c,t}^P = \gamma (1 - \alpha_c) \tilde{M} C_t \frac{Y_t}{N_{c,t}} \quad (C.17)$$

$$\tilde{W}_{c,t}^I = (1 - \gamma) (1 - \alpha_c) \tilde{M} C_t \frac{Y_t}{N'_{c,t}} \quad (C.18)$$

$$\tilde{R}_{c,t}^k = \alpha_c \tilde{M} C_t \frac{Y_t}{K_{c,t}} \quad (C.19)$$

Similarly the input demand from the housing sector (3.31)-(3.34) in real

term are:

$$\tilde{W}_{h,t}^P = \gamma (1 - \alpha_h - \alpha_l) q_t \frac{IH_t}{N_{h,t}} \quad (\text{C.20})$$

$$\tilde{W}_{h,t}^I = (1 - \gamma) (1 - \alpha_h - \alpha_l) q_t \frac{IH_t}{N'_{h,t}} \quad (\text{C.21})$$

$$\tilde{R}_{h,t}^k = \alpha_h \frac{q_t IH_t}{K_{h,t}} \quad (\text{C.22})$$

$$\tilde{R}_t^l = \alpha_l q_t IH_t \quad (\text{C.23})$$

Price setting

Non-housing firms maximization condition for the optimal price setting problem (3.25) is:

$$\mathbb{E}_t \sum_{s=0}^{\infty} (\zeta_p \beta^P)^s \left(\frac{\lambda_{t+s}^{I,P}}{\lambda_t^{I,P}} \right) (X_{t,s})^{-\frac{1+\lambda_f}{\lambda_f}} \left\{ \left[-P_t^{rel} (X_{t,s}) + (1 + \lambda_f) \tilde{M} C_{t+s} \right] \right\} = 0 \quad (\text{C.24})$$

where $X_{t,s} = \frac{\prod_{g=1}^s (\pi)^{(1-i_p)(\pi_{t+g-1})^{i_p}}}{\prod_{g=1}^s \pi_{t+g}}$ and the relative price P_t^{rel} is defined as $P_t^{rel} = \frac{P_t^{new}}{P_t}$, where P_t^{new} is the new price chosen by those firms able to re-optimize their price.

Price evolution (3.27) can be rewritten in terms of relative price as:

$$(1 - \zeta_p) (P_t^{rel})^{-\frac{1}{\lambda_f}} + \zeta_p \left(\frac{\pi_{t-1}^{\iota_p} \pi^{(1-\iota_p)}}{\pi_t} \right)^{-\frac{1}{\lambda_f}} = 1 \quad (\text{C.25})$$

C.2.2 Equilibrium conditions

The model equilibrium is described by the set of equations (C.1)-(C.25), (3.3), (3.4), (3.17)-(3.20), (3.28)-(3.30), and (3.35)-(3.50) and the definition of effective capital for both sectors provided in the section 3.2.3 of the main text.

C.2.3 Steady states

Combining (C.4) and (C.5) gives:

$$\lambda^{K_c} = \lambda^{I,P} = \lambda^{K_h} \quad (\text{C.26})$$

From (C.6) and using (C.26) and the fact that $a(u_h) = 0$ and $u_h = 1$ yields an expression for the rental rate of capital in the housing sector:

$$R_h^k = \frac{1}{\beta^P} - (1 - \delta_{kh}) \quad (\text{C.27})$$

Similarly from (C.7) the rental rate of capital in the non housing sector is:

$$R_c^k = \frac{1}{\beta^P} - (1 - \delta_{kc}) \quad (\text{C.28})$$

From (C.1):

$$\lambda^{I,P} = \frac{(1 - \beta^P h)}{C^P (1 - h)} \quad (\text{C.29})$$

Assuming at steady state inflation is zero, the steady state level of the nominal interest rate can be derived from (C.2)

$$R = \frac{1}{\beta^P} \quad (\text{C.30})$$

Equation (C.3), after substituting for $\lambda^{I,P}$ using (C.29), implies that the steady state value of housing wealth for patient households is:

$$qH^P = \frac{j(1 - h)}{[1 - \beta^P(1 - \delta_h)](1 - \beta^P h)} C^P \equiv A_1 C^P \quad (\text{C.31})$$

Equations (C.8) and (C.9) yields:

$$a'(u_c) = R_c^k \quad (\text{C.32})$$

$$a'(u_h) = R_h^k \quad (\text{C.33})$$

Under the assumption of full capital utilization at steady state the effective capital coincides with the stock of capital:

$$K_c = \overline{K}_c \quad (\text{C.34})$$

$$K_h = \overline{K}_h \quad (\text{C.35})$$

From (3.3), using $S_c(1) = 0$ and combining with (C.34) gives the steady state level of business investment in the non housing sector:

$$I_c = \delta_{kc} K_c \quad (\text{C.36})$$

Similarly from (3.4) the steady state level of business investment in the housing sector is:

$$I_h = \delta_{kh} K_h \quad (\text{C.37})$$

From (C.10)

$$\lambda^{I,I} = \frac{(1 - \beta^I h)}{C^I (1 - h)} \quad (\text{C.38})$$

From (C.11) and using (C.30) to substitute for R , the steady state level of the shadow value of borrowing is:

$$\lambda^B = \left(1 - \frac{\beta^I}{\beta}\right) \lambda^{I,I} \quad (\text{C.39})$$

From (C.12) and using (C.30), (C.38) and (C.39) the housing wealth value for impatient households is:

$$qH^I = \frac{j(1 - h^I)}{\{1 - \beta^I(1 - \delta_h) - (\beta^P - \beta^I)m\}(1 - \beta^I h)} C^I \equiv A_2 C^I \quad (\text{C.40})$$

From the impatient budget constraint (C.13)

$$C^I + qH^I \delta_h + T^I = \left(1 - \frac{1}{\beta^P}\right) B^I + W_c^I N_c^I + W_h^I N_h^I \quad (\text{C.41})$$

From impatient borrowing constraint (C.14) combined with (C.30), the value of borrowing at steady state is

$$B^I = m\beta qH^I \quad (\text{C.42})$$

Multiplying the housing market clearing condition (3.41) by the steady state level of real houses price q and using (C.31) and (C.40), follows that the aggregate value of residential investment is:

$$qIH = \delta_h (A_1 C^P + A_2 C^I) \quad (\text{C.43})$$

From (3.40) follows that the steady state level of output in the non-housing sector is:

$$Y = C^P + C^I + I_c + I_h + G \quad (\text{C.44})$$

Whereas, given the definition of GDP in (3.36), the GDP steady state value is:

$$GDP = C^P + C^I + I_c + I_h + qIH + G \quad (\text{C.45})$$

Using the input demand from firms in the non-housing sector (C.17) and (C.18) is possible to derive the steady state wage bill for both households:

$$N_c^I W_c^I = MC (1 - \gamma) (1 - \alpha_c) Y \quad (\text{C.46})$$

$$W_c^P N_c^P = MC \gamma (1 - \alpha_c) Y \quad (\text{C.47})$$

Similar, for the housing sector, using (C.20) and (C.21) combined with (C.43) yields:

$$W_h^I N_h^I = (1 - \gamma) (1 - \alpha_h - \alpha_l) \delta_h (A_1 C^P + A_2 C^I) \quad (\text{C.48})$$

$$W_h^P N_h^P = \gamma (1 - \alpha_h - \alpha_l) \delta_h (A_1 C^P + A_2 C^I) \quad (\text{C.49})$$

Plugging (C.43) into (C.22) yields the steady state value of capital in the

housing sector:

$$K_h = \frac{\alpha_h}{R_h^k} \delta_h (A_1 C^P + A_2 C^I) \quad (C.50)$$

Plugging the equation above into (C.37) gives the steady state level of business investment in the housing sector:

$$I_h = \delta_{kh} \frac{\alpha_h}{R_h^k} \delta_h (A_1 C + A_2 C') \quad (C.51)$$

From (C.19) the steady state level of capital in the non-housing sector is:

$$K_c = \alpha_c \frac{MC}{R_c^k} Y \quad (C.52)$$

Substitute into (C.36) gives the steady state level of business investment in the non-housing sector.

$$I_c = \alpha_c \delta_{kc} \frac{MC}{R_c^k} Y \quad (C.53)$$

In order to derive an expression for the steady state level of consumption for patient and impatient households combine the budget constraint (C.41) and the market clearing condition (C.44). Put (C.42), (C.46) and (C.48) into (C.41) and using (C.40) yields:

$$\begin{aligned} \{1 + m(1 - \beta) A_2 + \delta_h A_2 - (1 - \gamma)(1 - \alpha_h - \alpha_l) \delta_h A_2\} \frac{C^I}{Y} = & \quad (C.54) \\ + MC(1 - \gamma)(1 - \alpha_c) + (1 - \gamma)(1 - \alpha_h - \alpha_l) \delta_h A_1 \frac{C^P}{Y} - \frac{T^I}{Y} \end{aligned}$$

Put (C.51) and (C.53) into (C.44), divide by Y and solving for $\frac{C^P}{Y}$ yields:

$$\frac{C^P}{Y} = \left\{ 1 + A_1 \delta_{kh} \frac{\alpha_h}{R_h^k} \delta_h \right\}^{-1} \left\{ 1 - \left\{ 1 + \delta_{kh} \frac{\alpha_h}{R_h^k} \delta_h A_2 \right\} \frac{C^I}{Y} - \alpha_c \delta_{kc} \frac{MC}{R_c^k} - \frac{G}{Y} \right\} \quad (C.55)$$

Plug into (C.54) and rearranging gives:

$$\begin{aligned} \frac{C^I}{Y} &= PP_4 MC (1 - \gamma) (1 - \alpha_c) \\ &+ PP_4 PP_1 A_1 \{1 + A_1 PP_2\}^{-1} \left\{ 1 - \alpha_c \delta_{kc} \frac{MC}{R_c^k} - \frac{G}{Y} \right\} - PP_4 \frac{T^I}{Y} \end{aligned} \quad (C.56)$$

where:

$$PP_4 = \left[\begin{array}{c} 1 + m (1 - \beta) A_2 + \delta_h A_2 - PP_1 A_2 \\ + PP_1 A_1 \{1 + A_1 PP_2\}^{-1} \{1 + PP_2 A_2\} \end{array} \right]^{-1}$$

$$PP_1 = (1 - \gamma) (1 - \alpha_h - \alpha_l) \delta_h$$

$$PP_2 = \delta_{kh} \frac{\alpha_h}{R_h^k} \delta_h .$$

From (3.38) and using (C.30) follows:

$$\frac{T}{Y} = \left(\frac{1}{\beta} - 1 \right) \frac{D}{Y} + \frac{G}{Y} \quad (C.57)$$

Assuming both households pay the same amount of tax, in aggregate level must be:

$$\frac{T^I}{Y} = (1 - \gamma) \frac{T}{Y} \quad (C.58)$$

Equilibrium condition (C.15) for patient households labour supply in the non-housing sector implies:

$$W_c^P = (1 + \lambda_w) \psi^P \frac{N_{c,t}^{P\varphi}}{\lambda^{I,P}} \quad (C.59)$$

Plug into (C.47) and use (C.29) to substitute for $\lambda^{I,P}$:

$$N_c^P = \left[\frac{MC \gamma (1 - \alpha_c) (1 - \beta^P h)}{(1 + \lambda_w) \psi^P \frac{C^P}{Y} (1 - h)} \right]^{\frac{1}{1+\varphi}} \quad (C.60)$$

Similarly for housing sector plugging labour supply condition in (C.49) and simplifying using (C.29) yields:

$$N_h^P = \left[\frac{\gamma (1 - \alpha_h - \alpha_l) \delta_h \left(A_1 \frac{C^P}{Y} + A_2 \frac{C^I}{Y} \right) (1 - \beta^P h)}{(1 + \lambda_w) \psi^P \frac{C^P}{Y} (1 - h)} \right]^{\frac{1}{1+\varphi}} \quad (\text{C.61})$$

Thus, the aggregate level of hours N^P for patient agent is:

$$\begin{aligned} N^P &= N_h^P + N_c^P = \left[\frac{\gamma (1 - \alpha_h - \alpha_l) \delta_h \left(A_1 \frac{C^P}{Y} + A_2 \frac{C^I}{Y} \right) (1 - \beta^P h)}{(1 + \lambda_w) \psi^P \frac{C^P}{Y} (1 - h)} \right]^{\frac{1}{1+\varphi}} \\ &\quad + \left[\frac{MC \gamma (1 - \alpha_c) (1 - \beta^P h)}{(1 + \lambda_w) \psi^P \frac{C^P}{Y} (1 - h)} \right]^{\frac{1}{1+\varphi}} \end{aligned} \quad (\text{C.62})$$

One can always chose ψ^P such that the aggregate level of hours worked N^P is equal to 1/3. Solving equation above for ψ^P yields:

$$\begin{aligned} \psi^P &= \left[\frac{(1 - \beta^P h) \gamma}{\frac{C^P}{Y} (1 - h) (1 + \lambda_w)} \right] \times \\ &\quad \left\{ 3 \left[\left[(1 - \alpha_h - \alpha_l) \delta_h \left(A_1 \frac{C^P}{Y} + A_2 \frac{C^I}{Y} \right) \right]^{\frac{1}{1+\varphi}} + [MC (1 - \alpha_c)]^{\frac{1}{1+\varphi}} \right] \right\}^{1+\varphi} \end{aligned} \quad (\text{C.63})$$

Similarly, for impatient households

$$\begin{aligned} \psi^I &= \left[\frac{(1 - \beta^I h) (1 - \gamma)}{\frac{C^I}{Y} (1 - h) (1 + \lambda_w)} \right] \times \\ &\quad \left\{ 3 \left[\left[(1 - \alpha_h - \alpha_l) \delta_h \left(A_1 \frac{C^P}{Y} + A_2 \frac{C^I}{Y} \right) \right]^{\frac{1}{1+\varphi}} + [MC (1 - \alpha_c)]^{\frac{1}{1+\varphi}} \right] \right\}^{1+\varphi} \end{aligned} \quad (\text{C.64})$$

Finally, use (C.46), (C.47), (C.48) and (C.49) to derive an expression for wages steady state levels:

$$\frac{W_c^I}{Y} = \frac{MC(1-\gamma)(1-\alpha_c)}{N_c^I} \quad (\text{C.65})$$

$$\frac{W_c^P}{Y} = \frac{MC\gamma(1-\alpha_c)}{N_c^P} \quad (\text{C.66})$$

$$\frac{W_h^I}{Y} = \frac{(1-\gamma)(1-\alpha_h-\alpha_l)\delta_h\left(A_1\frac{C^P}{Y} + A_2\frac{C^I}{Y}\right)}{N_h^I} \quad (\text{C.67})$$

$$\frac{W_h^P}{Y} = \frac{\gamma(1-\alpha_h-\alpha_l)\delta_h\left(A_1\frac{C^P}{Y} + A_2\frac{C^I}{Y}\right)}{N_h^P} \quad (\text{C.68})$$

C.2.4 Log-linearized equilibrium

The log-linearized equilibrium conditions around the steady state, assuming inflation is zero and where appropriate expressing variable in real terms, are:

$$(1-h)(1-\beta^Ph)\widehat{\lambda}_t^{I,P} = -(1+\beta^Ph^2)\widehat{c}_t^P + h\widehat{c}_{t-1}^P + \beta^Ph\mathbb{E}_t\widehat{c}_{t+1}^P \quad (\text{C.69})$$

$$\widehat{\lambda}_t^{I,P} = \mathbb{E}_t\widehat{\lambda}_{t+1}^{I,P} + \widehat{r}_t - \mathbb{E}_t\widehat{\pi}_{t+1} \quad (\text{C.70})$$

$$\begin{aligned} \widehat{q}_t = & -[1-\beta^P(1-\delta_h)]\left(\widehat{h}_t^P - \widehat{\lambda}_t^{I,P}\right) - \beta^P(1-\delta_h)(\widehat{r}_t - \mathbb{E}_t\widehat{\pi}_{t+1}) \\ & + \beta^P(1-\delta_h)\mathbb{E}_t\widehat{q}_{t+1} \end{aligned} \quad (\text{C.71})$$

$$(1+\beta^P)\widehat{i}_{h,t} = \frac{(\widehat{\lambda}_t^{K_h} - \widehat{\lambda}_t^{I,P})}{S_h''(1)} + \widehat{i}_{h,t-1} + \beta^P\mathbb{E}_t\widehat{i}_{h,t+1} \quad (\text{C.72})$$

$$(1+\beta^P)\widehat{i}_{c,t} = \frac{(\widehat{\lambda}_t^{K_c} - \widehat{\lambda}_t^{I,P})}{S_c''(1)} + \widehat{i}_{c,t-1} + \beta^P\mathbb{E}_t\widehat{i}_{c,t+1} \quad (\text{C.73})$$

$$\begin{aligned}\widehat{\lambda}_t^{K_h} - \widehat{\lambda}_t^{I,P} &= -(\widehat{r}_t - \mathbb{E}_t \widehat{\pi}_{t+1}) + (1 - \beta^P (1 - \delta_{kh})) \mathbb{E}_t \widehat{r}_{h,t+1}^k \\ &\quad + \beta^P (1 - \delta_{kh}) \left(\mathbb{E}_t \widehat{\lambda}_{t+1}^{K_h} - \mathbb{E}_t \widehat{\lambda}_{t+1}^{I,P} \right)\end{aligned}\quad (\text{C.74})$$

$$\begin{aligned}\widehat{\lambda}_t^{K_c} - \widehat{\lambda}_t^{I,P} &= -(\widehat{r}_t - \mathbb{E}_t \widehat{\pi}_{t+1}) + (1 - \beta^P (1 - \delta_{kc})) \mathbb{E}_t \widehat{r}_{c,t+1}^k \\ &\quad + \beta^P (1 - \delta_{kc}) \left(\mathbb{E}_t \widehat{\lambda}_{t+1}^{K_c} - \mathbb{E}_t \widehat{\lambda}_{t+1}^{I,P} \right)\end{aligned}\quad (\text{C.75})$$

$$R_c^k \widehat{r}_{c,t}^k = a''(1) \widehat{u}_{c,t} \quad (\text{C.76})$$

$$R_h^k \widehat{r}_{h,t}^k = a''(1) \widehat{u}_{h,t} \quad (\text{C.77})$$

$$(1 - \beta^I h) (1 - h) \widehat{\lambda}_t^{I,I} = - (1 + \beta^I h^2) \widehat{c}_t^I + h \widehat{c}_{t-1}^I + \beta^I h \mathbb{E}_t \widehat{c}_{t+1}^I \quad (\text{C.78})$$

$$\widehat{\lambda}_t^{I,I} = \left(1 - \frac{\beta^I}{\beta^P} \right) \widehat{\lambda}_t^B + \frac{\beta^I}{\beta^P} \mathbb{E}_t \left[\widehat{\lambda}_{t+1}^{I,I} + \widehat{r}_t - \widehat{\pi}_{t+1} \right] \quad (\text{C.79})$$

$$\begin{aligned}\widehat{\lambda}_t^{I,I} + \widehat{q}_t &= - \{ 1 - \beta^I (1 - \delta_h) - (\beta^P - \beta^I) m \} \widehat{h}_t^I \\ &\quad + \beta^I (1 - \delta_h) \left(\widehat{\lambda}_{t+1}^{I,I} + \widehat{q}_{t+1} \right) \\ &\quad + (\beta^P - \beta^I) m \mathbb{E}_t \left[\widehat{\lambda}_t^B + \widehat{q}_{t+1} + \widehat{\pi}_{t+1} - \widehat{r}_t \right]\end{aligned}\quad (\text{C.80})$$

$$\begin{aligned}\frac{C^I}{Y} \widehat{c}_t^I - m \beta^P A_2 \frac{C^I}{Y} \widehat{b}_t^I + A_2 \frac{C^I}{Y} \delta_h \widehat{q}_t + A_2 \frac{C^I}{Y} \left[\widehat{h}_t^I - (1 - \delta_h) \widehat{h}_{t-1}^I \right] + \frac{T^I}{Y} \widehat{t}_t^I &= \\ -m A_2 \frac{C^I}{Y} \left(\widehat{r}_{t-1} - \widehat{\pi}_t + \widehat{b}_{t-1}^I \right) + M C (1 - \gamma) (1 - \alpha_c) (\widehat{w}_{c,t}^I + \widehat{n}_{c,t}^I) & \\ + (1 - \gamma) (1 - \alpha_h - \alpha_l) \delta_h \left(A_1 \frac{C^P}{Y} + A_2 \frac{C^I}{Y} \right) (\widehat{w}_{h,t}^I + \widehat{n}_{h,t}^I) &\end{aligned}\quad (\text{C.81})$$

$$\widehat{b}_t^I = \mathbb{E}_t \left(\widehat{q}_{t+1} + \widehat{h}_t^I + \widehat{\pi}_{t+1} - \widehat{r}_t \right) \quad (\text{C.82})$$

$$\begin{aligned} \widehat{w}_{l,t}^{d,rel} &= \zeta_{l,w} \beta^d \mathbb{E}_t \left\{ \widehat{w}_{l,t+1}^{d,rel} + \widehat{w}_{l,t+1}^d - \widehat{w}_{l,t}^d - i_{w,l} \widehat{\pi}_t + \widehat{\pi}_{t+1} \right\} \\ &+ \frac{\lambda_w (1 - \zeta_{l,w} \beta^d)}{\lambda_w + (1 + \lambda_w) \varphi} \left\{ \varphi \widehat{n}_{l,t}^d - \widehat{\lambda}_t^{I,d} - \widehat{w}_{l,t}^d \right\} \end{aligned} \quad (\text{C.83})$$

$$\widehat{w}_{l,t}^d = i_{w,l} \widehat{\pi}_{t-1} - \widehat{\pi}_t + \widehat{w}_{l,t-1}^d + \frac{(1 - \zeta_{l,w})}{\zeta_{l,w}} \widehat{w}_{l,t}^{d,rel} \quad (\text{C.84})$$

$$\widehat{w}_{c,t}^P = \widehat{m}c_t + \widehat{y}_t - \widehat{n}_{c,t}^P \quad (\text{C.85})$$

$$\widehat{w}_{c,t}^I = \widehat{m}c_t + \widehat{y}_t - \widehat{n}_{c,t}^I \quad (\text{C.86})$$

$$\widehat{r}_{c,t}^k = \widehat{m}c_t + \widehat{y}_t - \widehat{k}_{c,t} \quad (\text{C.87})$$

$$\widehat{q}_t + i\widehat{h}_t - \widehat{n}_{h,t}^P = \widehat{w}_{h,t}^P \quad (\text{C.88})$$

$$\widehat{w}_{h,t}^I = \widehat{q}_t + i\widehat{h}_t - \widehat{n}_{h,t}^I \quad (\text{C.89})$$

$$\widehat{r}_{h,t}^k = \widehat{q}_t + i\widehat{h}_t - \widehat{n}_{h,t} \quad (\text{C.90})$$

$$\widehat{r}_t^l = \widehat{q}_t + i\widehat{h}_t \quad (\text{C.91})$$

$$\widehat{\pi}_t = \frac{\iota_p}{(1 + \iota_p \beta)} \widehat{\pi}_{t-1} + \frac{\beta^P}{(1 + \iota_p \beta^P)} \mathbb{E}_t [\widehat{\pi}_{t+1}] + \frac{(1 - \zeta_p \beta^P) (1 - \zeta_p)}{\zeta_p (1 + \iota_p \beta^P)} \widehat{m}c_t \quad (\text{C.92})$$

$$\widehat{\widehat{k}}_{c,t} = (1 - \delta_{kc}) \widehat{\widehat{k}}_{c,t-1} + \delta_{kc} \widehat{I}_{c,t} \quad (\text{C.93})$$

$$\widehat{\widehat{k}}_{h,t} = (1 - \delta_{kh}) \widehat{\widehat{k}}_{h,t-1} + \delta_{kh} \widehat{I}_{h,t} \quad (\text{C.94})$$

$$y_t = \widehat{a}_t + (1 - \alpha_c) \left[\gamma (\widehat{x}_{c,t}^P + \widehat{n}_{c,t}^P) + (1 - \gamma) (\widehat{x}_{c,t}^I + \widehat{n}_{c,t}^I) \right] + \alpha_c \widehat{k}_{c,t} \quad (\text{C.95})$$

$$\widehat{a}_t = \rho_a \widehat{a}_{t-1} + \varepsilon_t^a \quad (\text{C.96})$$

$$\widehat{x}_{c,t}^P = \rho_x \widehat{x}_{c,t-1}^P + \mu_n \widehat{n}_{c,t-1}^P \quad (\text{C.97})$$

$$\widehat{x}_{c,t}^I = \rho_x \widehat{x}_{c,t-1}^I + \mu_n \widehat{n}_{c,t-1}^I \quad (\text{C.98})$$

$$\widehat{i}h_t = (1 - \alpha_h - \alpha_l) \left[\gamma \left(\widehat{x}_{h,t}^P + n_{h,t}^P \right) + (1 - \gamma) \left(\widehat{x}_{h,t}^I + \widehat{n}_{h,t}^I \right) \right] + \alpha_h \widehat{k}_{h,t} \quad (\text{C.99})$$

$$\widehat{x}_{h,t}^P = \rho_x \widehat{x}_{h,t-1}^P + \mu_n \widehat{n}_{h,t-1}^P \quad (\text{C.100})$$

$$\widehat{x}_{h,t}^I = \rho_x \widehat{x}_{h,t-1}^I + \mu_n \widehat{n}_{h,t-1}^I \quad (\text{C.101})$$

$$\widehat{r}_t = \rho_r \widehat{r}_{t-1} + (1 - \rho_r) \left[\phi_\pi \widehat{\pi}_t + \phi_{gdp} \left(\widehat{gdp}_t - \widehat{gdp}_{t-1} \right) \right] + \varepsilon_t^r \quad (\text{C.102})$$

$$\begin{aligned} \frac{GDP}{Y} \widehat{gdp}_t &= \frac{C^P}{Y} \widehat{c}_t^P + \frac{C^I}{Y} \widehat{c}_t^I + \frac{I_c}{Y} \widehat{i}_{c,t} + \frac{I_h}{Y} \widehat{i}_{h,t} \\ &+ \delta_h \left(A_1 \frac{C^P}{Y} + A_2 \frac{C^I}{Y} \right) \widehat{i}h_t + \frac{G}{Y} \widehat{g}_t \end{aligned} \quad (\text{C.103})$$

$$\widehat{g}_t = \rho_a \widehat{g}_{t-1} + \varepsilon_t^g \quad (\text{C.104})$$

$$\frac{G}{Y} \widehat{g}_t + \frac{1}{\beta} \frac{D}{Y} \left(\widehat{r}_{t-1} + \widehat{d}_{t-1} - \widehat{\pi}_t \right) = \frac{T}{Y} \widehat{t}_t + \frac{D}{Y} \widehat{d}_t \quad (\text{C.105})$$

$$\widehat{t}_t = \Psi_{gdp} \widehat{gdp}_t + \Psi_d \widehat{d}_{t-1} \quad (\text{C.106})$$

$$\widehat{y}_t = \frac{C^P}{Y} \widehat{c}_t^P + \frac{C^I}{Y} \widehat{c}_t^I + \frac{I_c}{Y} \widehat{i}_{c,t} + \frac{I_h}{Y} \widehat{i}_{h,t} + \frac{K_c}{Y} R_c^k \widehat{u}_{c,t} + \frac{K_h}{Y} R_{h,t}^k \widehat{u}_{h,t} + \frac{\widehat{G}}{Y} \widehat{g}_t \quad (\text{C.107})$$

$$\begin{aligned} \delta_h \left(A_1 \frac{C^P}{Y} + A_2 \frac{C^I}{Y} \right) \hat{h}_t &= A_1 \frac{C^P}{Y} \left[\hat{h}_t^P - (1 - \delta_h) \hat{h}_{t-1}^P \right] \\ &\quad + A_2 \frac{C^I}{Y} \left[\hat{h}_t^I - (1 - \delta_h) \hat{h}_{t-1}^I \right] \end{aligned} \quad (C.108)$$

$$(C^P + C^I) \hat{c}_t = C^P \hat{c}_t^P + C^I \hat{c}_t^I \quad (C.109)$$

$$(I_c + I_h) \hat{c}_t = I_c \hat{c}_{c,t} + I_h \hat{c}_{h,t} \quad (C.110)$$

$$(W_h^P + W_h^I) \hat{w}_{h,t} = W_h^P \hat{w}_{h,t}^P + W_h^I \hat{w}_{h,t}^I \quad (C.111)$$

$$(W_c^P + W_c^I) \hat{w}_{c,t} = W_c^P \hat{w}_{c,t}^P + W_c^I \hat{w}_{c,t}^I \quad (C.112)$$

$$(N_h^P + N_h^I) \hat{n}_{h,t} = \gamma N_h^P \hat{n}_{h,t}^P + (1 - \gamma) N_h^I \hat{n}_{h,t}^I \quad (C.113)$$

$$(N_c^P + N_c^I) \hat{n}_{c,t} = \gamma N_c^P \hat{n}_{c,t}^P + (1 - \gamma) N_c^I \hat{n}_{c,t}^I \quad (C.114)$$

$$(W_h + W_c) \hat{w}_t = W_h \hat{w}_{h,t} + W_c \hat{w}_{c,t} \quad (C.115)$$

$$(N_h + N_c) \hat{n}_t = N_h \hat{n}_{h,t} + N_c \hat{n}_{c,t} \quad (C.116)$$

$$\hat{t}_t^P = \gamma \hat{t}_t \quad (C.117)$$

$$\hat{t}_t^I = (1 - \gamma) \hat{t}_t \quad (C.118)$$

$$\hat{k}_{c,t} = \hat{u}_{c,t} + \hat{k}_{c,t-1} \quad (C.119)$$

$$\hat{k}_{h,t} = \hat{u}_{h,t} + \hat{k}_{h,t-1} \quad (C.120)$$

C.3 Initial guess and estimated values

As already discussed in the appendix A.4, the optimization routine employed is able to find only a local minimum. I performed 300 draws to verify that my estimates are actually a global minimum. For about 30% of them the initial guess is a local minimum. However, the value of loss function as defined in equation (1.38) is extremely large compared to the value of loss function for the parameter reported in section 3.5. I therefore discard these estimates since they do not appear to be a local minimum. For the remaining cases, the initial guess and the corresponding final estimates are reported in figures C.1-C.3. The draws are sorted in ascending order by the value of the loss function. As figures show, my optimization routine converges to the same values in most cases.

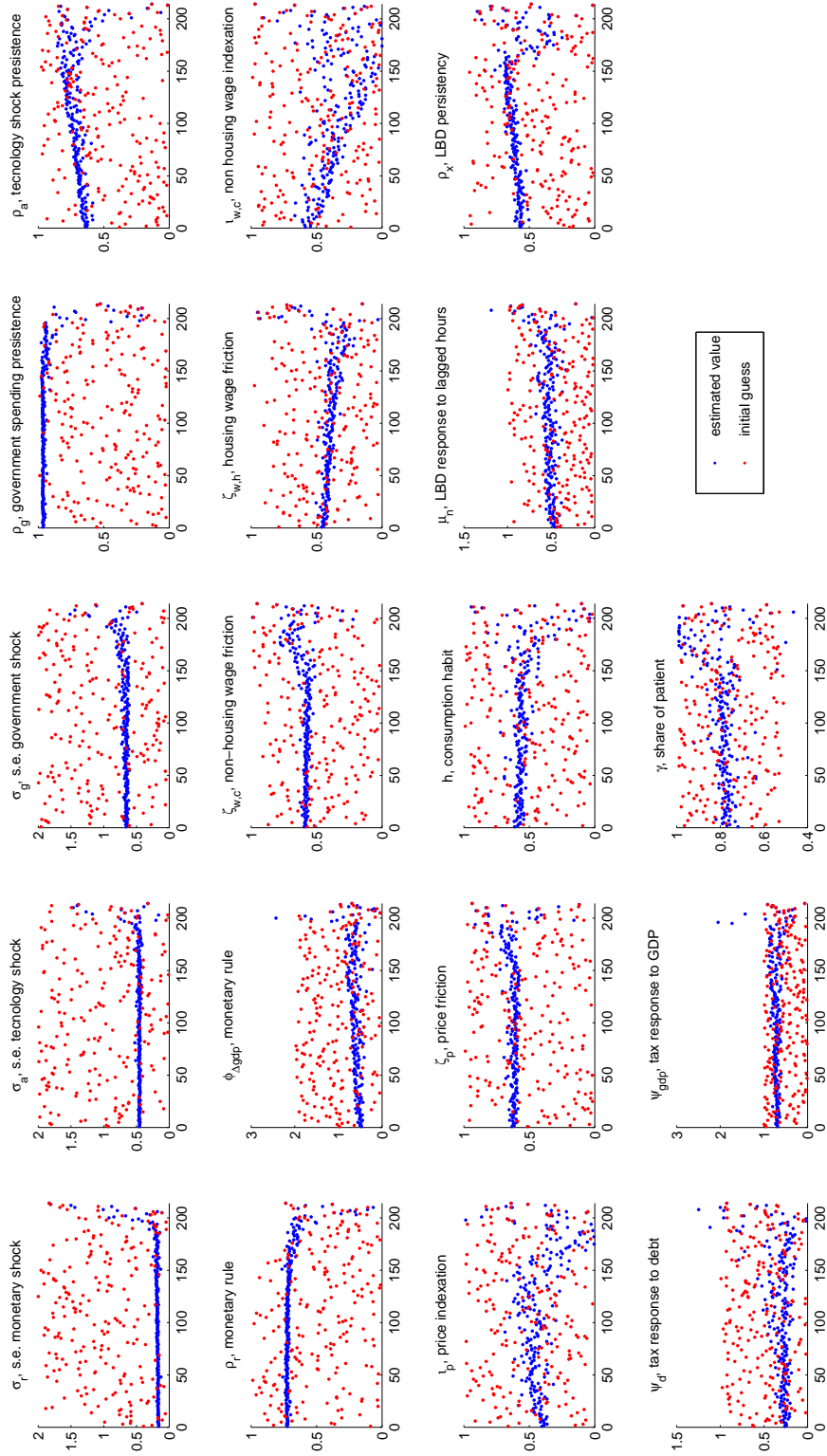


Figure C.1: Estimation sensitivity analysis: initial guess and obtained estimates. Baseline model.

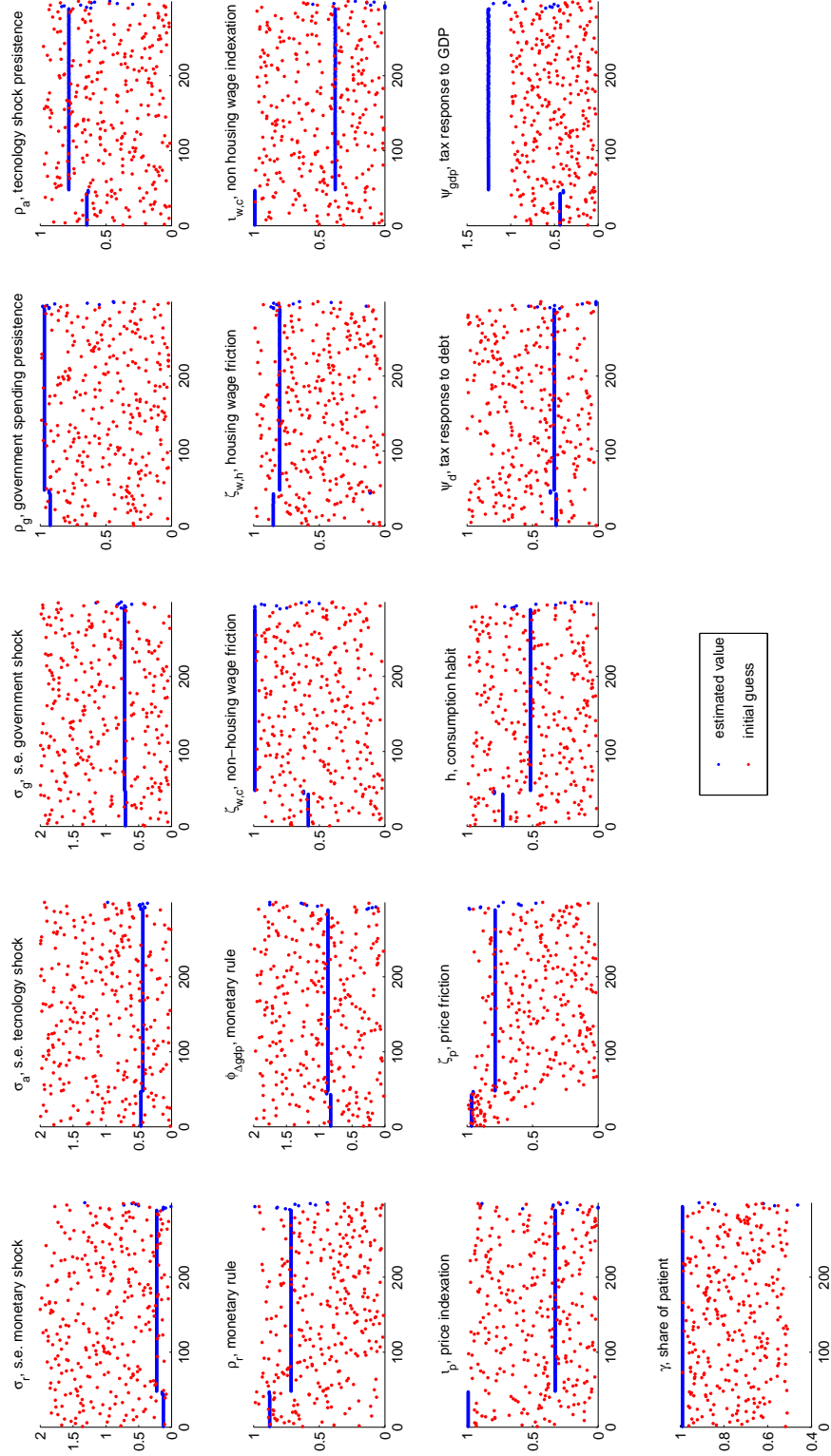


Figure C.2: Estimation sensitivity analysis: initial guess and obtained estimates. Model without LBD.

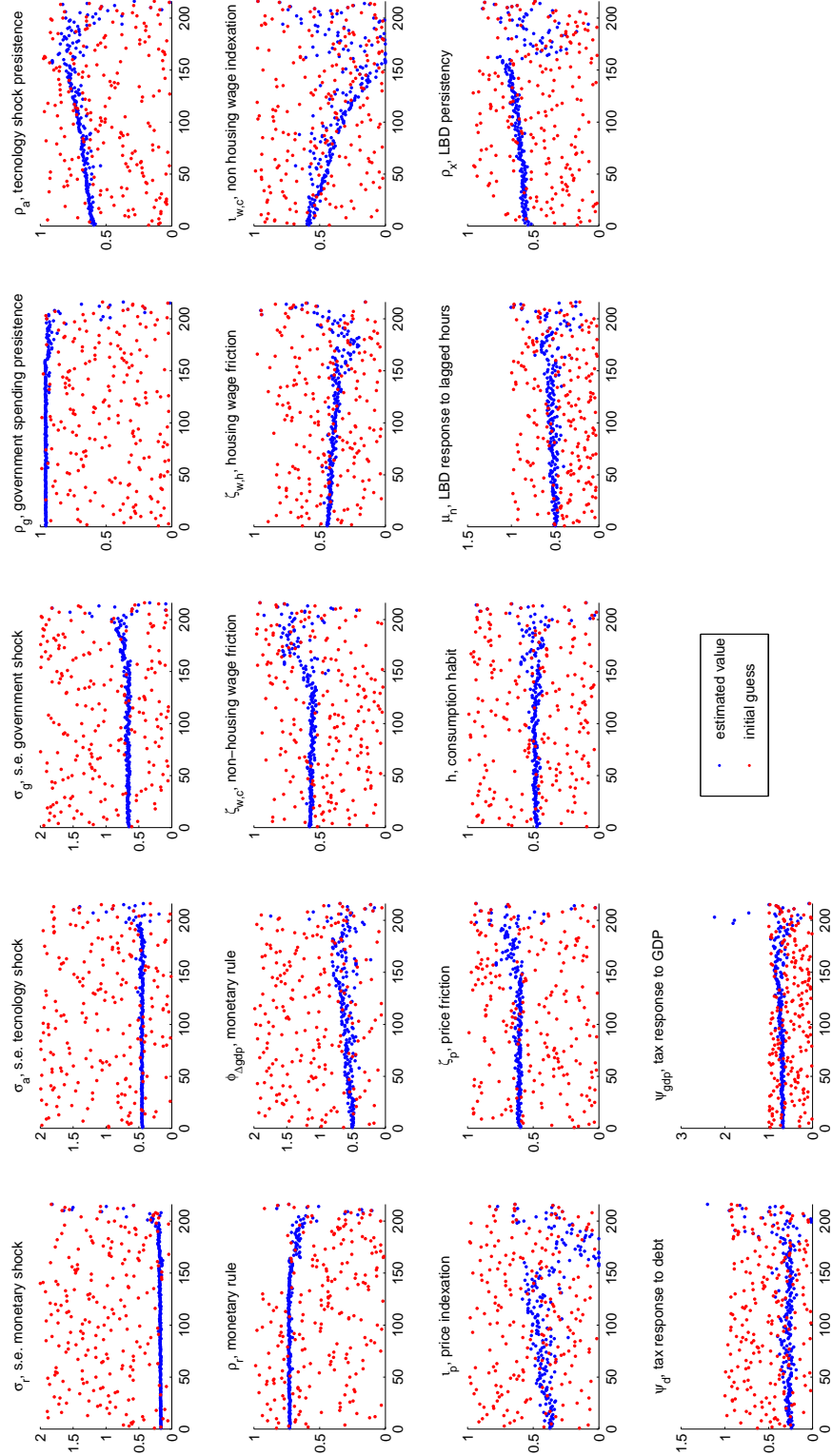


Figure C.3: Estimation sensitivity analysis: initial guess and obtained estimates. Model without collateral channel.

Conclusions

This thesis contributes to the ongoing debate on the effects and propagation mechanisms of government spending shocks on economic activity. I investigate the theoretical and empirical relevance of a propagation mechanism for government spending shocks based on skill accumulation of workers through past work experience or Learning-by-Doing (LBD). LBD is perceived as external by households and firms.

The main results found in the thesis are the following.

First, in chapter 1, I conduct a structural vector auto-regression (VAR) analysis using US data to illustrate that an expansionary government spending shock increases private consumption, productivity and real wages and is associated with a fall in inflation and interest rates. I show that a New Keynesian DSGE model with LBD can account for all these facts, whereas without LBD the model delivers results at odds with the data. The DSGE model is estimated by minimising the distance between the DSGE and VAR impulse response functions. After the model has been estimated, I investigate whether it is capable of accounting for some of the facts regarding the behaviour of GDP and other variables over the business cycle in the United States.

Second, in chapter 2, I demonstrate the capability of LBD to explain the persistent depreciation of the real exchange rate in response to an expansionary government spending shock. The international risk sharing condition yields a strong correlation between domestic consumption and the real exchange rate. The decline in the real interest rate, due to the increase in productivity, generates a persistent real exchange rate depreciation, whereas the DSGE model

without LBD leads to a counterfactual appreciation of the real exchange rate.

Finally, in chapter 3, I study the effect of a government spending shock on the housing market. VAR evidences for the US show that a positive government spending shock increases real house prices. In the presence of credit constrained agents that can borrow against the value of their housing wealth, the increase in house price introduces an additional propagation mechanism for a government spending shock. The increase in the collateral's value raises the amount credit constrained agents can borrow to finance their consumption expenditure. I show that, introducing LBD, the reduction in the real interest rate yields a rise in house prices. The collateral channel amplifies the response of consumption to a government shock. Absent LBD, the model cannot mimic the observed increase in real house price and consumption in response to an expansionary government spending shock. The model is estimated using the VAR/DSGE impulse responses matching approach.

The introduction of LBD is a promising solution in explaining the sign of the response to a government spending shock for the variables considered. However, its quantitative relevance is open to question.

In many cases the variables in the DSGE model are less responsive to shocks than the corresponding variables in the VAR model. As result, the baseline DSGE model is not able to account for the fluctuations in the economic activity and it is able to explain only a fraction of the volatility observed in the data. These limitations ask for further research to explore the implications of LBD.

The analysis performed in the thesis could consider different periods of time and be extended to other countries to verify whether there exist relevant differences across time and space.

In this thesis I have considered LBD as a pure externality. It would be interesting to investigate the implications for the model when the accumulation of skills is internalized in the firms as organizational capital.

A further improvement of the model could be achieved by incorporating labour market frictions within the search and matching framework *à la* Mortensen and Pissarides. The introduction of this feature could make the model able to distinguish between hours vary on the extensive and intensive margin, since only the latter is relevant for the LBD. Furthermore, search and

matching frictions would allow to consider workers job-specific skills.

Finally, it would be useful to consider alternative econometric strategies to identify the VAR model and estimate the DSGE model. The methodology employed to estimate the DSGE structural parameters is based on the assumption that the VAR model is correctly identified. Further analysis should be carried out to verify the robustness of this assumption.

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